LABORATORY EXERCISES

TO ACCOMPANY

CARHART AND CHUTE'S FIRST PRINCIPLES OF PHYSICS

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INTRODUCTORY

SUGGESTIONS TO THE INSTRUCTOR

Selection of Experiments

Scope of the Experiments. — The experiments in this book provide a wide range of laboratory work for an elementary course in Physics. The exercises have been selected on the basis of their educational value to the student. Their aim is to impart to him certain fundamental principles, to acquaint him with some physical phenomena qualitative in character, and to show the operation and the use of practical devices or instruments that are applications of physical principles.

The authors have not hesitated to omit from their list certain well-known experiments which have persisted in many elementary courses, rather by inertia than because of any special interest or value to the beginner. On the other hand, it is impossible to include in a small book all the experiments of merit suitable to a first course in Physics. Yet, from those given, it will be possible for any instructor to make a selection of the experiments which the great majority of Physics teachers include in their courses, so as to afford a well-balanced laboratory training, both interesting and instructive to the student.

Recommended Lists. — Only the institutions most favored as to laboratory time will be able to complete in one scholastic year all the experiments outlined in this book. Any choice of experiments must depend upon the apparatus available and upon the laboratory conditions. To fit the usual laboratory equipment and to meet the time limitations of most first courses in the subject, the authors suggest the following list of thirty-five experiments as affording a good training in those

fundamentals of the science most suitable for laboratory instruction:

Fundamental Course

Mechanics: Exercises 3, 4, 8, 9, 10, 11, 19, 23, 25, 26, 27.
Sound: Exercise 35.
Light: Exercises 37, 38, 39, 42, 43, 46, 47.
Heat: Exercises 51, 58, 59, 61, 62.
Magnetism and Electricity: Exercises 66, 68, 69, 70, 80, 81, 82, 83, 84, 85, 89.

The following ten exercises will supplement the above, particularly for those students whose ability enables them to do a maximum amount of work:

Mechanics, 6, 13 or 14, 28, 29;
Sound, 34;
Light, 44;
Heat, 57;
Magnetism and Electricity, 72, 78 (or other experiment on resistance), 90.

The following sixty exercises are suggested as a more extended course for those institutions favored with about double the laboratory time usually allotted to the first course:

Extended Course

Mechanics: Exercises 1, 3, 4, 6, 8, 9, 10, 11, 15, 16, 17, 19, 20, 23, 24, 25, 26, 27, 28, 29, 30.
Sound: Exercises 32, 34, 35.
Light: Exercises 37, 38, 39, 42, 43, 44, 46, 47, 48.
Heat: Exercises 51, 52, 57, 58, 59, 60, 61, 62, 63.
Magnetism and Electricity: Exercises 65, 66, 68, 69, 70, 72, 73, 78, 79, 80, 81, 82, 83, 84, 85, 86, 89, 90.

The authors recommend the following list of experiments for girls, especially for those not intending to go beyond the high school. Most of these experiments have been selected because of their close relationship to the practical affairs of life.

Mechanics: Exercises 1, 2, 3, 6, 8, 9, 12 (or 13 or 14), 17, 18, 23, 26, 27, 28.

Sound: Exercises 34 (or 35), 36.

Light: Exercises 37, 38, 39, 49, 50.

Heat: Exercises 51, 52, 59, 60, 61, 64.

Magnetism and Electricity: Exercises 65, 68, 70, 79, 80, 82, 83, 84.

A number of interesting and valuable experiments do not appear in any of the preceding lists, but it is hoped that some of them will be taken from time to time either as substituted or as additional exercises. A limited amount of variation from year to year adds interest and vitality to any laboratory course. Many of the experiments just referred to will meet the needs of those instructors who desire to give more time to certain divisions of the subject.

Order of Experiments. — The order in which the divisions of the subject are taken should depend upon the aim of the course and the conditions under which it is given. In their own work the authors find the most satisfactory order to be Mechanics, Heat, Sound, Electricity, and Light. In most syllabi, however, the subject of Light precedes that of Electricity. In the view of many, the experiments on Heat are best adapted to the student's powers after he has finished the experiments in Mechanics.

Time required for Experiments. — A majority of the experiments are designed to take from 80 to 90 minutes of laboratory time, including the writing of the note-book record. Some of the shorter ones will require but half of that time, or a single school period. Even if a double laboratory period is not available for the longer experiments, the directions have been written so that the experiments can be done successfully in two single periods. The system recommended for the note-book record saves time in securing the observational data. Especial care has been taken not to overload the student with more manipulations and observations than would be reasonable for an average rate of work within the time allotment.

The Experimental Directions

Aim. — At first sight it may seem that the directions for the experiments have been written in a rigid form which may hamper the individuality of the teacher using them. With the possible exception of the placing of the tables of observations and calculated results, it will be found that the directions and their requirements are in accord with the usages which have become generally established as leading to intelligent and efficient laboratory work.

The five main divisions of the printed directions are "Introductory," "Experimental," "Calculated Results," "Discussion," and "Conclusion." Certain suggestions as to these divisions appear in the paragraphs that follow.

Introductory. — The paragraphs under this heading in the printed directions serve several purposes. First, they awaken the student's interest in the problem to be studied by reference to applications of Physics more or less familiar to him. Secondly, the introductory statements show the relation between the practical applications and the laboratory problem to be solved. In some cases the paragraphs furnish a little theoretical information, necessary for the intelligent performance of the experiment. All that is required of the student is that he read and understand this introductory matter — usually a task of a few minutes. It is not expected nor is it desired that the introductory matter be copied into the note-book.

The authors offer no apology for the paragraphs introductory to the experiments. They have simply put in written form those preliminary remarks that many instructors find desirable to make when the class assembles for the experiment. It is felt that the written form has the advantage of being always available for the student's reference.

Experimental. — Whenever the length and character of the experiment permits, the laboratory problem is presented as a whole to the student. With the general plan in mind, he is able to do the experiment with greater self-reliance and effi-

ciency than can be obtained from the slavish following of detailed directions with little grasp of their intent.

In some experiments, however, detailed directions must be given to secure the successful imparting of a series of experimental facts. In such cases the divisions are made as few as possible and their meaning made clear by brief directions, a little supplementary information, and questions that the average student should be able to answer from his experimental observations.

The students are directed to place the data gathered in the experiment in a *table of observations* near the top of the *left-hand* page of the note-book record. The form for this table is usually furnished, and it is strongly recommended that the student write the form in the note-book before making any of the measurements. This procedure provides for the orderly recording of the data as soon as it is obtained, and insures the completion of the experimentation within the laboratory hour. There is economy also of the instructor's time, as he can quickly note the rate of progress of the individual and check inaccuracies in the readings.

With most experiments only one set of readings is indicated in the tables of observations, but the instructor desiring more can increase the number of columns at the right. In the opinion of the authors, much time is wasted by requiring the duplication of readings by the elementary student of Physics, unless in work where personal errors are large.

Drawings. — After the observations are completed, the student is directed to make sectional or outline drawings from his apparatus so as to show that he understands its arrangement and operation. Many of the illustrations in this book have been made from drawings made by students in the regular course of their laboratory work. Such drawings will indicate to the users of this book the methods of representing laboratory apparatus by simple outline drawings. The development of a simple scheme of sectional representation is within the power of any student and will prove most useful to him.

Descriptions. — The table of observations and the sectional drawings render unnecessary long and elaborate descriptions of the experimental work. All that is asked is a brief but clear statement of the general method of the experiment and the recording of any experimental facts not shown by the drawings nor provided for in the table of observations. In the last few years it has become more and more recognized that the chief function of the laboratory note-book is to show the essentials of an experiment and not to provide useless drudgery for the student.

Calculated Results. — Preceding the table of calculated results occurring in many experiments, are found directions for making the calculations. The authors have not hesitated to furnish information to aid the student in making the calculations when these are rendered more intelligible thereby.

The directions call for the placing of the *table of calculated results* at the top of the *right-hand* page of the note-book record. The calculations themselves should be made directly below the table. These requirements secure prominent and convenient locations for the making of the computations and the orderly recording of the results. The student can tell from the tabular form what is expected of him in the way of calculations and knows when his work is finished. The instructor is enabled to check quickly the recorded results and to point out during the laboratory period sources of error.

Discussions. — Under this division the student is directed to answer any italicized questions occurring in the experimental directions or the questions under the printed heading, Discussion. Thus the theoretical considerations of the experiment are brought together ready for reference or correction.

Conclusions. — The student is either required to state for himself the formal conclusion justified by the experimental facts, or to complete a partial statement by filling in the indicated blanks. The latter method is preferred in those cases where a complete and well-worded conclusion is difficult for

the student to formulate. The vital part of the statement must be furnished by the student and requires thought on his part.

Method of Laboratory Work. — Many of the advantages of having the note-book record follow a definite plan have been discussed under the topics preceding this. Tabular forms for the observations and the calculated results are appreciated by many instructors as leading to that economy of laboratory time which gives the best opportunity for experimentation and reflection. The forms for such tabulations may be written in the note-book prior to the laboratory hour and the general plan of the experiment studied.

The authors believe that it is not only permissible, but highly desirable, for the student to know before he comes into the laboratory what he is to do. They require their own students to carefully study the experiment and to write the blank table of observations in the note-book before coming to the laboratory. Except in the case of very complicated experiments, the student is not allowed to have the experimental directions before him until he has taken all readings and completed his drawing and description. He is then allowed to refer to his direction sheet for guidance as to his calculations and conclusions. It has been found that under this plan the work in the laboratory is more intelligent and less of the "cook-book" order. Furthermore, schools having only single laboratory periods may be certain of having the readings taken and the experiment described during the laboratory period, while calculated results and conclusions may be worked out the next day either in laboratory or classroom, or, if desired, done as part of the home lesson for the day following that of the laboratory period.

No factor contributes more to the success of a laboratory course than having the apparatus tested and entirely ready for the student when he enters the laboratory. Then only is it possible for him to put the apparatus together and start its operation without loss of time, so that the readings can be made comfortably within the period.

Note-book Directions. — On page 16 there will be found brief instructions intended for the student and relating to the form of the note-book record. Any orderly plan must have definiteness; so it becomes necessary to designate left-hand and right-hand pages for certain purposes. These directions may reverse the usage of some instructors, but it is hoped that they will realize it makes little difference whether the left-hand page or the right-hand page serves a certain purpose, so long as there is a definite systematic plan to make the note-book record a help to the student, and to make the ever present and laborious task of note-book correction easier for the instructor.

DIRECTIONS TO STUDENTS

Balances

Construction of Platform Balances. — The platform balance or trip scale is a simple, equal arm lever in which the vertical displacement of either arm is indicated by a pointer swinging across a horizontal scale. When the pointer swings approximately equal distances on each side of the center division on the horizontal scale, the two lever arms are balanced and the scale is said to be in equilibrium.

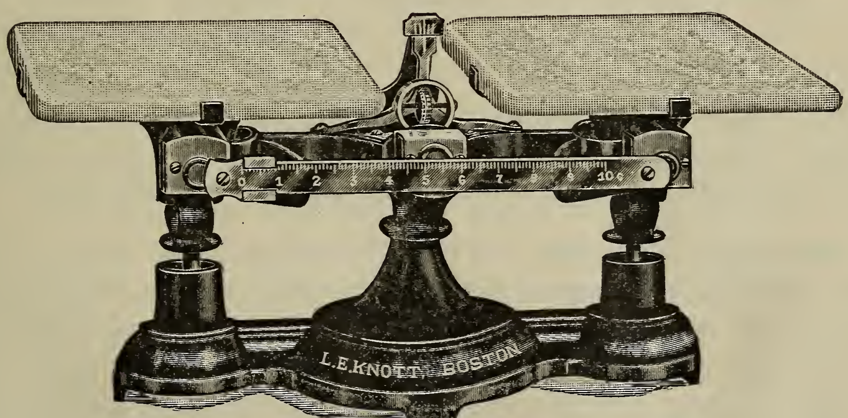


Fig. 1. Platform Balance.

The construction of the trip scale is shown in Figs. 1 and 2 on this and the following page. This convenient instrument for weighing is too often misused in the physical laboratory and poor results obtained with it. With the observance, however, of a few simple precautions, rapid, accurate weighings can be made with this piece of apparatus.

Adjustment of Platform Balances. — Before weighing always see that both platforms are clean. Then touch lightly one

platform and note whether or not the pointer swings freely and equally on each side of the center line of the scale. The pointer should oscillate at least two divisions to the right and to the left. In too short swings the friction in the bearings makes the scale relatively less sensitive. Therefore the pointer's coming to rest at the center point is no sure indication that the two arms of the scale are balanced or in equilibrium.

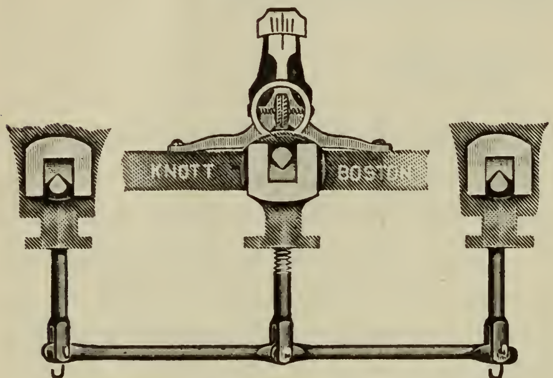


Fig. 2. Sectional View of Balance.

In case the pointer swings to a distinctly greater distance on one side of center, turn the thumb nut which is just below the center, so that the nut moves a little distance towards the side of the lesser swing. Again note the swings. When they are approximately equal on both sides of center, the scale is adjusted for weighing.

Handling of Weights. — Place the *object* to be weighed on the *left-hand* platform or pan and the *weights* on the *right-hand* platform. In adding or removing weights, prevent with the left hand the movement of the pans until the change of weights has been made. In this way avoid jarring the balance and injuring the knife-edges.

For the first weight select the one which in your opinion is about equal to the object being weighed. If this weight is too small, take it off and replace it with the next larger one. Continue in this way until you have the largest weight which is lighter than the object. Then add the next smaller weight. Time-saving weighing means the systematic use of the next smaller or the next larger weight, as the case may be, until the scale is balanced.

In practice the graduated beam with its rider enables one to

dispense with the smaller weights. If the beam is graduated for 5 grams, the 1-gram and the 2-gram weights are not used; with a 10-gram beam, the weights below 10 grams are not necessary. By means of the graduated beam, these smaller weights are found by moving the rider to the right until the balance is in equilibrium. Note carefully on which side of the rider the reading should be made, and remember that the reading can be made to *tenths* of a gram.

When the correct weight is obtained, count carefully the weights on the right-hand pan and add the weight indicated on the beam. Record this total weight at once in the laboratory note-book.

Return the weights to their block, or case, counting as you do so. Add the weight indicated on the beam and check the weight recorded in the note-book. Remove the object from its scale pan. A scale left with the arms unequally balanced soon loses its sensitiveness, owing to unnecessary wear on the bearings.

Beam Balances. — Another form of balance much used in the physical laboratory is the beam balance. The beam in this case rests at its center point on a knife-edge, or a wedge, supported on a vertical stand. Pans are suspended on the ends of the beam either by hooks, or in the more expensive kinds by stirrups which rest on knife-edges. A vertical pointer indicates on a small graduated scale the oscillations of the beam. Some beam balances have on one arm of the beam a rider, which slides along a graduated scale and thus indicates the smaller weights. To avoid dulling the knife-edges, there is often a device which lifts the beam off the knife-edges when the balance is not in use. The pan arrest similarly lifts the bow and stirrup suspension from off the knife-edges on the ends of the beam.

The *specific gravity balance* is usually a beam balance which has a shorter suspension for one of the pans. From a hook on the under side of this pan are suspended objects which are to be weighed in a liquid.

The *hornpan balance* is simply a beam balance, which is supported vertically from a hook hung on a ring stand or held by the hand.

Spring Balances. — A spring balance measures the mass of a body by the elongation of a spiral spring. The weight is indicated on a graduated scale by a pointer attached to a drawbar on the free end of the spring. Attached to the drawbar is a hook on which is suspended the object to be weighed.

The spring balance is made to read correctly in vertical position, with the hook downward. The weight of the drawbar and hook should be sufficient to bring the pointer to the zero mark on the graduated scale. If the pointer does not stand at zero with no load on the balance, a correction must be made to the weight registered on the scale in order to get the true weight of the object. The inconvenience of making these corrections may sometimes be avoided by wrapping about the shank of the hook a strip of sheet lead, sufficient in weight to bring the pointer to the zero point of the scale.

The friction in a spring balance tends to make less accurate the readings in the first portion of the graduated scale. At the other end of the scale, when the spring is near its maximum stretch, the elongations are not quite proportional to the heavier weights added. Accordingly the most accurate readings with a spring balance are those obtained in about the middle portion of the graduated scale.

In some experiments the spring balance is used to measure the pull or force exerted upon its spring. When used for this purpose it is termed a *dynamometer*.

Sensitiveness of a Balance. — The sensitiveness of a balance may be defined as the smallest difference which is indicated by the balance with a given load. The trip scale should be sensitive to at least the tenth of a gram with an ordinary load, *i.e.* show a difference between 50.6 and 50.7 grams. A good hornpan balance indicates weights within the hundredth of a gram (1 centigram) while an accurate chemical balance is sensitive to a ten-thousandth of a gram (tenth of a milligram).

Relative Advantages of Platform and Beam Balances. — The platform balance, while it is easy to keep clean and can stand much usage, is usually not so sensitive as the beam balance. The broad platforms, however, are very convenient for weighing bulky, unstable objects, and the oscillations of its beam are easily controlled.

The sensitiveness of a beam balance is gained at the expense of stability and durability, for the beam is easily displaced and the knife-edge suspension becomes dulled by use. On this account great care should be taken not to jar the balance nor allow the beam to oscillate too rapidly. The weights should be placed gently upon the pans and removed when the pans are at rest (*i.e.* supported by the pan arrest or by the hand).

Were it not for the awkwardness and carelessness of some students, the beam balance would always be most desirable for rapid, accurate weighings in the physical laboratory.

Electrical Measuring Instruments

The instruments used for measuring the strength or the pressure of an electric current have very delicate parts and may be easily ruined by either rough usage or excessive current.

Before using any galvanometer or other meter the student should assure himself that it has the proper scale range and current-carrying capacity for the work in hand. He must further so connect his apparatus that the instrument will not be upset or pulled out of place by any change in connections made during the experiment. As the several instruments that the student may be called to use in his experiments differ in their sensitiveness, method of connection, and method of reading, each kind will be briefly discussed by itself. In reading all instruments, tenths of the smallest divisions should be estimated.

Tangent Galvanometer. — This consists of a compass needle mounted at the center of a hoop, on which is wound the wire

which is to convey the current. This is the most rugged of the instruments, but the pivot is likely to be bent by dropping or violently jarring the instrument. Where there are a number of binding posts, to permit the use of different numbers of turns of wire, find out from the instructor which posts to use and the number of turns of wire included between them. In order to read the instrument accurately, it should be so placed on the table that it will be possible to look directly down on the needle. The instrument should be carefully turned until the needle is in the plane of the coil.

D'Arsonval Galvanometer. — The moving part of this instrument is a light coil of wire, suspended between the poles of a permanent magnet by a fine wire or ribbon through which the current passes. This suspension is exceedingly thin, so that even a slight shock to the instrument will break it and a comparatively small current will melt it. The instrument is commonly provided with a clamping device which takes the weight of the coil off the suspension when the galvanometer is not in use.

In setting up the galvanometer, keep the coil clamped until you are ready to connect to the source of current. Then make sure that the instrument is leveled in such a way that the coil does not rub against any part of the instrument but hangs perfectly free. The method of reading the deflections for the particular instrument you are using will be explained by the instructor.

It is exceedingly important that only a *very small current* pass through the coil of the instrument. On this account, the galvanometer should have either a coil of high resistance in series with it or a low resistance shunt across the terminals for most experiments. Such additions to the instrument should be made either by the instructor previous to the laboratory hour or under his immediate direction by the student.

Ammeter. — The commercial form of this instrument is usually a d'Arsonval galvanometer provided with a shunt of

such resistance that the deflections of the needle give the number of amperes directly. The coil is pivoted instead of being suspended, but the instrument must be guarded against falls and shocks just as a fine watch would be.

Before connecting the ammeter in circuit, be sure that its range is sufficient for the current to be measured. If the instrument has more than one range, always connect for the largest range first, and then change the connections to those for a smaller range, if the readings indicate that this can be safely done.

If the ammeter has an *external shunt*, be sure that the connections between the shunt and the instrument movement are tight. A loose contact will certainly make an incorrect reading and may burn out the instrument.

Connect the terminals of the instrument *in series* with the circuit. If connected in shunt with the other apparatus, the resistance of the instrument is so small that the movement will probably be burned out.

In every electrical circuit, there should be a switch that can be opened instantly if there is the slightest indication of too much current for the instruments or any other part of the apparatus.

Voltmeter. — This is similar to the ammeter in construction, but has a high resistance in series with the movement instead of a shunt across the movement. The voltmeter measures pressure, while the ammeter measures current flow.

The same precautions for handling and for the selection of a proper scale range are to be observed as in the case of the ammeter.

Connect the voltmeter *across* (in shunt with) the circuit or that part of the circuit in which the voltage drop is to be measured.

Resistance Box. — The voltage applied to a resistance box should never be great enough to cause more than 0.1 ampere to pass through the box.

The Laboratory Note-book

Unless other directions are given by the instructor, the following plan should be followed in recording experiments in the note-book.

Number of Experiment. — Place to the left and at the top of the *left-hand* page.

Date of Experiment. — Place to the right and at the top of the left-hand page.

Title. — Place immediately below the number and date.

Object. — Place directly below the title.

Tables of Observations. — Place immediately below the object. In case the instructor desires the duplication of the observations, make the necessary number of parallel columns at the right. Always record the measurements, *as soon as made*, in the tabular form. Decimals should be used, rather than common fractions.

The number, the date, the title, the object, and the table of observations should be written in the note-book *before* the experimental work is begun.

Drawings. — Place on the left-hand page clear sectional drawings showing the arrangement and operation of your apparatus. In making a sectional drawing, imagine a vertical plane passing through the middle of your apparatus; then imagine your paper to be in the position of this plane. Draw lines where the paper would touch the intersected apparatus.

Descriptions. — Place these usually on the left-hand page and shorten your work by referring to your drawings. A simple, clear account of the general method of the experiment is preferable to an elaborate description.

Table of Calculations. — Place at the top of the *right-hand* page *before* making any of the calculations. Do the mathe-

matical work involved, immediately below the table, and record the results *as soon as obtained* in the tabular form.

Discussion. — Under this heading on the right-hand page, answer any italicized questions occurring in the experimental directions as well as the questions under the printed heading of "Discussion." If more room is necessary, continue on the *next* right-hand page.

Conclusion. — Place under this heading on the right-hand page, immediately following the Discussion.

Introductory. — It will pay you to read and understand this, before beginning the experimental work. It is not to be copied into the laboratory note-book.

LABORATORY EXERCISES

EXPERIMENT 1

Metric Units of Measurement

OBJECT. To become familiar with the units of metric measurements commonly used in scientific work.

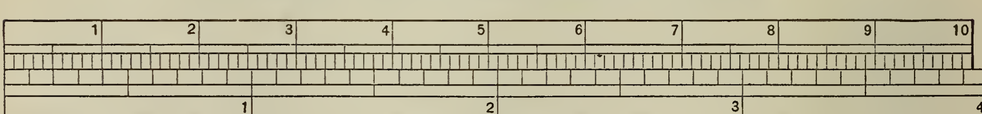
APPARATUS. Meter stick; scissors; small graduate (50 or 100 c.c.); large graduate (500 or 1000 c.c.); liquid quart measure; small wide-mouth bottle; tumbler; platform balance; metric weights; 1 lb. weight.

MATERIAL. "Oak tag," or some other kind of stiff paper; mucilage, or paste.

Introductory:

The Metric System is the official system of units of measurement in most civilized countries. It is the system used in scientific work in the United States. The unit

100 MILLIMETERS = 10 CENTIMETERS = 1 DECIMETER = 3.937 INCHES.



INCHES AND TENTHS

Fig. 3.

of this system is the *meter*, and standard bars with this distance marked on them are preserved for reference by various governments.

The Metric System is a decimal system and therein lies its great convenience. The meter is subdivided into

ten parts, each of which is termed a *decimeter;* the hundredth of a meter is a *centimeter;* the thousandth of a meter, a *millimeter.* From these fundamental units, the units of surface, volume, and weight are derived.

The meter measures 39.37 inches.

Experimental:

At the top of the *left-hand page* of the laboratory note-book put the *number* and *title* of the experiment and the *date.* Then state the *object* of the experiment. Immediately below this, put the following tabular form for the readings:

OBSERVATIONS

Length of note-book cover	*cm.*
Width of note-book cover	*cm.*
Metric equivalent of liquid quart	*cm.*^{3}
Capacity of small bottle	*cm.*^{3}
Capacity of tumbler	*cm.*^{3}
Weight of note-book	*g.*
Metric equivalent of a pound	*g.*

Units of Length. — (*a*) Examine a meter stick, noting its subdivisions. In your laboratory note-book, just below the table of observations, rule horizontal lines of the following lengths, labeling each line with its length:

1 decimeter, 1.1 decimeters, 1.5 decimeters, 5 centimeters, 2.5 centimeters, 1.3 centimeters, 1 centimeter.

(*b*) Measure in centimeters and tenths of a centimeter the length of the cover of your laboratory note-book. Similarly measure the width. Record the dimensions.

Units of Volume and Capacity. — (*c*) On a separate piece of paper, lay off a diagram like Fig. 4.

Cut around the diagram with a pair of scissors. Bend over the little flaps and fold into a cube, pasting the flaps on the inside so as to hold the cube together.

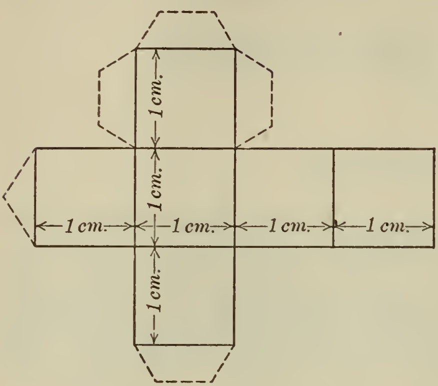


Fig. 4.

The little cube, if accurately made, is a *cubic centimeter*, the unit of volume. 1000 cubic centimeters give the *liter*, the unit of capacity. For convenience, the measuring instruments for liquids are usually cylindrical vessels, marked off in cubic centimeters and known as *graduates*.

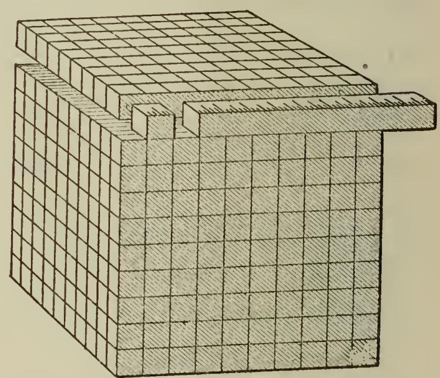


Fig. 5. Dissected Liter Block.

(*d*) Using a large graduate, determine how many cubic centimeters of water are needed to fill an ordinary quart measure.

(To be done in groups of four students unless otherwise directed by the instructor.)

(*e*) Using a small graduate, find the capacity in cubic centimeters of the small bottle furnished you.

Similarly determine the capacity of an ordinary drinking tumbler.

Units of Weight. — The weight of a cubic centimeter of water at its maximum density (4° C.) is taken as the unit of weight, the *gram*.

1000 grams make a *kilogram*, a weight used for measuring large quantities.

(*f*) Using a platform balance, find the weight in grams of your laboratory note-book. Record.

(*g*) Determine how many grams are needed to counterbalance an ordinary pound weight. Record.

Tables for the calculated results should be placed at the top of the *right-hand* page of the note-book, and the calculations worked out just beneath them.

Express the number of cubic centimeters found in (*d*) as the decimal part of a liter. Using this number, calculate the equivalent of a liter in quarts, carrying the result to two decimal places.

Calculate from the comparison of weights found in (*g*), the equivalent of a kilogram in pounds and tenths of a pound.

Calculated Results

1 *liter*	*qts.*
1 *kilogram*	*lbs.*

Discussion:

In what respects was the convenience of the Metric System shown in your measurements? Place the answer to this question on the right-hand page of the note-book, heading it "Discussion." (Under this heading are to be written the answers to any italicized questions occurring in the experimental directions.)

EXPERIMENT 2

Properties of Materials

OBJECT. **To examine a few common substances so as to determine their properties.**

Apparatus. Triangular file; pocket-knife; hammer; anvil, or flatiron (with detachable handle).

MATERIAL. Copper wire #18, or some larger size; strips of sheet lead about $3\frac{1}{2}'' \times \frac{1}{2}''$; pieces of small glass tubing; paraffin; rubber bands, or strips of sheet rubber; steel nails.

Introductory:

Every substance has its own set of properties. Certain of these are the well-marked or characteristic properties by which we recognize the substance. These characteristic properties are important in that they determine the practical use of a substance.

Experimental:

The substances to be examined are copper, glass, rubber, lead, paraffin, wood, and steel. Take them in any order. Tabulate on the left-hand page of your note-book the results of your examination, in a table like that given below.

SUBSTANCE	HARDNESS	LUSTRE	MALLEABILITY	ELASTICITY
Copper				
Glass				
Rubber				
Lead				
Paraffin				
Wood				
Steel				

Hardness. — Use a knife blade or a file to determine the hardness. Describe this in comparative terms, as very soft, soft, somewhat hard, hard, and very hard.

Lustre. — Note two kinds of lustre or "shine." Which substances would be said to be without lustre?

Malleability. — Use a hammer, and tap the substance on an anvil or other block of iron to ascertain whether or not the substance can be hammered out into sheets without breaking.

Elasticity. — Try to change the shape of the substance by bending. If the substance bends or gives, remove the strain to find out whether or not the substance will return to its original condition. In determining the elasticity, make use of the results obtained in testing for malleability.

Ductility. — A ductile substance admits of being drawn out into fine wire. This property is not easily determined in the laboratory by students. *Which of the substances are ductile? Why do you think so?* Do not tabulate for ductility.

Write a simple description of how you determined each of the properties tabulated. No drawing is necessary for this experiment.

Discussion:

Under this heading on the right-hand page of notebook, answer any italicized questions occurring in the experimental directions, and also the following questions: Which of the substances are good conductors of heat? Of electricity? Name any other general properties that have not been mentioned in this experiment (Class Discussion).

EXPERIMENT 3

Measurement of Bodies

OBJECT. **To find in metric units the volume of a block of wood.**

APPARATUS. Wooden block; metric scale.

Introductory:

Iron is "heavier" or more dense than wood. To find out how many times as dense, measurements must be made of the size and weight of a piece of each. It is more convenient in physical work to make the measurements in the metric system, because it is a decimal system. The chief units used are the centimeter and the gram.

Experimental:

On the left-hand page of your note-book and immediately below the statement of the object of the experiment, put a tabular form like the following for the measurements to be made: [1]

OBSERVATIONS

Number of block	. . . .	
Length of block	. . . .	*cm.*
Width of block	. . . .	*cm.*
Thickness of block	. . . .	*cm.*

When the scale is placed so that the scale divisions touch the block, there will be less error in reading measurements.

[1] *Note to Instructor.* Many teachers find it desirable to have the students write in their laboratory note-books, previous to coming into the laboratory, the number, the title, and the object of the experiment, and any tabular form of measurements to be made. As this will be the first experiment in many courses, the directions for the note-book record have been made very definite.

The eye must be directly in front of the point on the scale and the point located in the block. *Why is it desirable to estimate to hundredths of a division on a scale divided into tenths?*

Using the scale in this way, find the length, breadth, and thickness of the block furnished you. Do not make measurements at bruised corners.

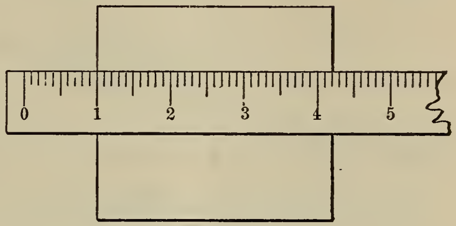


Fig. 6.

From your apparatus make, on the left-hand page of the note-book, an outline drawing similar to that given (Fig. 6).

On the same page write a brief description of what you did, touching on the points regarding measurements which you were instructed to observe. Complete in the laboratory at least the drawing and the description. The left-hand page of the note-book should be finished before the right-hand page is begun.

On the right-hand page, place the table of calculated results, the calculations themselves, the answers to the questions for discussion, and the formal conclusion. The tables of calculated results should always be placed at the top of the right-hand page.

Calculated Result

Volume of block . . . . *cm.*^{3}

In making the calculations for the above results, indicate the units of measurement for each result. Do not carry out the calculated volume beyond the hundredths of a cubic centimeter. Read the discussion on "Significant Figures," pages 27–29.

Discussion:

Under this heading on the right-hand page answer any italicized questions occurring in the experimental directions. Why would it be desirable to make several measurements of each dimension of the block and take the average for the calculation?

Conclusion:

The volume of block No. ..... is ...... $cm.^3$.

SIGNIFICANT FIGURES

Accuracy in Scientific Calculations. — Calculations in scientific work are based on readings obtained by some method of measurement. The calculations cannot be more accurate than the figures with which they are made. Yet beginners in physics, in their zeal to be accurate, retain figures in their calculations far beyond the point justified by the accuracy of the measurements. The results are not so accurate as they would be if certain figures had been discarded in the progress of the calculations. The following paragraphs aim to show how *scientific* accuracy may be obtained in the calculations of experimental physics.

Average Readings or Results. — The dimensions of a rectangular block may be measured with a metric scale graduated in centimeters and millimeters. By estimating the tenths of a millimeter, the readings may be expressed to the hundredths of a centimeter.

The following readings might be obtained for the length of the block as determined along two of its edges:

A	*B*
7.45 cm.	7.45 cm.
7.42 cm.	7.42 cm.
7.47 cm.	7.47 cm.
3)22.34 cm.	3)22.34 cm.
7.44 cm.	7.446 cm.
(Correct scientific average.)	(Incorrect scientific average.)

The second decimal place in these readings represents the estimated tenths of a millimeter. In estimating such small quantities, one may readily misjudge not only by one tenth of

a millimeter, but even to the extent of two or three tenths. Hence the figures expressing tenths of a millimeter are not accurate, but are doubtful figures. They are indicated here in heavy-face type.

In column *B* the average given for the three readings is 7.4**46**. In this number the second **4** is a doubtful figure, therefore the **6** in the next decimal place beyond must be *more than doubtful.* This figure **6** means nothing in our units of measurement.

Some authorities may claim that 7.45 is nearer to the correct average in such a case. Mathematically this is so, but it must be remembered that one cannot judge accurately between 0.04 cm. and 0.05 cm. on a scale whose smallest division is 0.1 cm. Hence the average of 7.4**4** in column *A* may be regarded by the painstaking student as correct and reasonable, particularly as the divisor is a small number.

Retention of Significant Figures. — Let us find the volume of a rectangular block with the following dimensions: length, 7.4**4** cm.; width, 4.6**7** cm.; and height, 2.8**2** cm. To find the area of the base multiply the length by the width, indicating the doubtful figures in heavy-face type.

7.4**4**
4.6**7**
5208
446**4**
297**6**
34.**7448** cm.²

In the first partial product, **5208**, all the figures are doubtful, as they were obtained by multiplying by the doubtful figure **7**; in the second partial product, 446**4**, the final **4** is doubtful because it resulted from a multiplication in which a doubtful figure was a factor; and for the same reason the **6** in the third partial product, 297**6**, is doubtful.

In the addition of the partial products, figures which are ob-

tained by adding doubtful figures, are doubtful figures. This makes the last four figures doubtful in the total 34.**7448**. All the doubtful figures but the *first* should be discarded. Then the area of the base as justified by the accuracy from measurements is 34.**7** square centimeters.

To find the cubical contents multiply the area of the base by the height:

$$\begin{array}{r} 34.\mathbf{7}\phantom{\text{ cm.}^3} \\ \underline{2.8\mathbf{2}}\phantom{\text{ cm.}^3} \\ \mathbf{694}\phantom{\text{ cm.}^3} \\ 277\mathbf{6}\phantom{\text{ cm.}^3} \\ 69\mathbf{4}\phantom{\text{ cm.}^3} \\ \hline 97.\mathbf{854}\text{ cm.}^3 \end{array}$$

Discarding all the doubtful figures except the first, 97.**8** cm.^{3} is the correct volume of the rectangular block.

A student who found the cubical contents without discard ing any of the doubtful figures would get as a result 97.980336 cm.^{3}. Not only would he have done extra work, but his result would not be scientifically accurate.

A good rule in making calculations is to *retain only significant figures.* Significant figures include the first doubtful figure and the figures preceding it.

EXPERIMENT 4

Volume Measurement of an Irregular Body

OBJECT. To find the volume of a body of irregular shape.

APPARATUS. Solid of irregular shape, as a lump of metal, brass hook weight (50 or 100 g.), or large-sized lead sinker; cylindrical graduate (100 c.c.); strong thread, or string.

Introductory:

The volume of a body of irregular shape cannot be found by measuring a few dimensions and then making a simple calculation. A stone dropped into a glass of water raises the water level. As the stone and the water cannot occupy the same place at the same time, the volume of the stone may be found from the *increase* in volume.

Experimental:

Given a lump of metal and a graduated cylinder with water in it, devise a way of getting the volume of the metal.

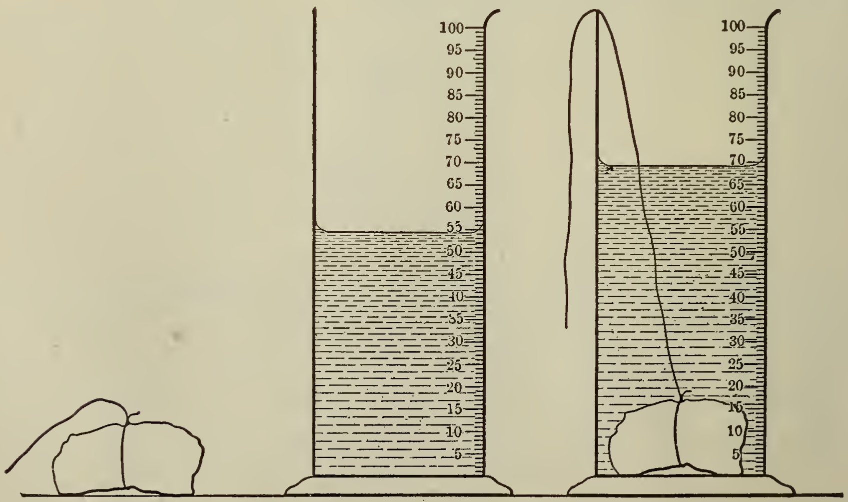


Fig. 7.

In reading a graduate, place the eye on the level of the lowest point of the curved surface and record this as the height of the water. As the graduations are cubic centimeters, and as an error of 1 cm.^{3} in the volume that we are measuring would be a considerable per cent of error, therefore, estimate tenths of a cubic centimeter as nearly as you can.

Make the readings indicated by the table of observations and record in a similar tabular form near the top of the left-hand page of note-book.

OBSERVATIONS

Reading before immersing the metal . . .	*cm.*^{3}
Reading after immersing the metal	*cm.*^{3}
Number of lump of metal	
Material of lump	

On the left-hand page of the note-book, make from your apparatus, outline drawings similar to Fig. 7, and write a simple description of the experimental method used.

Discussion:

What property of matter makes possible this method of finding the volume?

Conclusion:

Volume of lump of metal No. _____ is _____ cm.^{3} – _____ cm.^{3} = _____ cm.^{3}.

EXPERIMENT 5

Density

OBJECT. To determine the density of wood and of metal.

APPARATUS. Block used in Experiment 3; lump of metal used in Experiment 4; spring balance or other balance; linen thread.

Introductory:

Iron is heavier than wood and lead is heavier than iron. By this we mean that, if we take pieces of the three materials of the same size, the lead has the greatest weight, and so we conclude there are more pounds per cubic foot (or grams per cubic centimeter) of lead than of iron or of wood. That is, the lead has the greatest *density*, for density is the mass per unit volume of a substance. In the metric system this is written grams per cubic centimeter or $\frac{\text{g.}}{\text{cm.}^3}$.

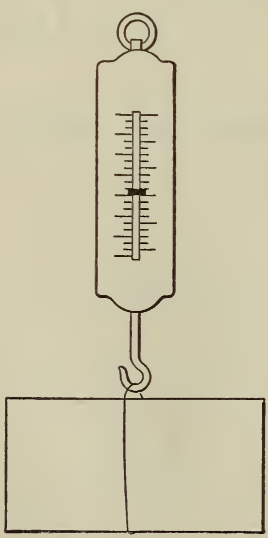


Fig. 8.

Experimental:

All that is necessary for the calculations is to know the mass and volume. The volume of each of the solids to be used has already been obtained in Experiments 3 and 4.

The mass of a body is measured by its weight. The greater the mass, the more a body will stretch a spring from which it is hung. The graduations on the scale of the spring balance indicate the masses that must be hung upon the hook, in order to pull the pointer

to each division on the scale. The mass of the block may be found, then, by hanging it upon a spring balance. Read the balance to tenths of the smallest division.

If a beam or a platform balance is used, read on page 11 or on page 9 the directions for its use before performing this experiment.

Observations

Mass of wood	*g.*
Mass of metal	*g.*

From your apparatus make, on the left-hand page of the note-book, an outline drawing like Fig. 8. On the same page write a simple description of what you did.

Make the calculations and put the results in a table at the top of the right-hand page of the note-book.

Calculated Results

Volume of block (*from Exp.* 3)	*cm.*^{3}
Volume of metal (*from Exp.* 4)	*cm.*^{3}
Density of wood	*g. per cm.*^{3}
Density of metal (_____)	*g. per cm.*^{3}

Conclusion:

The density of wood is _____

The density of _____ is _____
(name metal)

EXPERIMENT 6

Elasticity — Hooke's Law

OBJECT. To find the relation between the elongation of a spiral spring and the stretching force, provided the elastic limit is not exceeded.

APPARATUS. A closely coiled spiral about 10 cm. long and 1.7 cm. in diameter, made of #20 spring brass wire, with a hook and pointer at one end and at the other a straight section for hanging or clamping; stand with pendulum clamp and meter stick clamp; meter stick; pan for suspension; metric weights.[1]

Introductory:

When a steamboat makes its landing, the large hawsers tighten as the boat is swung toward the wharf. The diameter of the large rope becomes smaller and measurements would show the length had been stretched. The stretching force has changed both the shape and volume of the rope. When the the line is cast off again, the rope, because it is an elastic body, recovers very nearly its original diameter and length. Sometimes the stretching force is so great that the rope snaps because the ultimate strength of the rope has been exceeded.

In materials subjected to stretching forces, as the wire in the coil of a spring balance, the change in diameter is very slight, but there is considerable lengthening or *elongation*. The question arises whether the elongation proceeds irregularly or at a uniform rate as the stretching force increases, provided the elastic limit of the material is not exceeded.

[1] The spiral coil may be conveniently made by winding the wire around a $\frac{1}{2}''$ pipe. The special pendulum and meter stick clamps may be replaced with ordinary laboratory clamps or other attachments. In case weights heavier than those specified for the loads are used, a larger size of wire should be selected.

Experimental:

Place the meter stick in a vertical position. Suspend the weight pan on the hook of the spring and attach the pointer just above the hook at right angles to the spring. Suspend the spring so that the end of the pointer is close to the metric scale, but does not touch it. Also try to adjust the position of the spring so that the pointer is opposite some main division of the metric scale such as the 10-cm. or 20-cm. mark. This mark is the zero reading or the point from which the first elongation is to be measured. Record this zero reading.

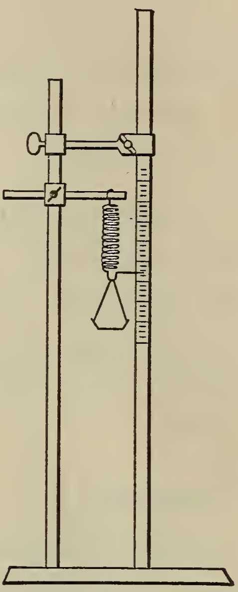


Fig. 9.

Put a 5-gram weight in the pan and read the position of the pointer. Take off this weight and allow the spring to go back. Again read the position of the pointer. Now put on the 10-gram weight. Continue in

OBSERVATIONS

LOAD ON PAN	READING OF POINTER	ZERO READING	CORRECTED READING (TOTAL ELONGATION)
5 grams	cm.	cm.	cm.
10 grams	cm.	cm.	cm.
15 grams	cm.	cm.	cm.
20 grams	cm.	cm.	cm.
25 grams	cm.	cm.	cm.
30 grams	cm.	cm.	cm.
35 grams	cm.	cm.	cm.
40 grams	cm.	cm.	cm.
45 grams	cm.	cm.	cm.
50 grams	cm.	cm.	cm.
55 grams	cm.	cm.	cm.
60 grams	cm.	cm.	cm.

this manner, increasing the load 5 grams at a time and recording the results in tabular form near the top of the left-hand page. The total elongation due to the load is the difference between the pointer reading and the zero reading which is made each time.

Make a drawing from your apparatus, and write a simple description of the experimental method.

Curve on Cross Section Paper. With the loads taken and the total elongations obtained, plot a curve on cross section paper, placing loads on the perpendicular axis and total elongations on the horizontal axis. Attach the cross section paper by one edge to the right-hand page of notebook.

Discussion :

What kind of a curve is obtained? What relation does this show between the total elongation and the stretching force? How elastic should the spring be in order to obtain very exact results? Was your spring such a spring? What is the principle upon which a spring balance works?

Conclusion :

Complete the following statement of Hooke's Law: When the elastic limit is not exceeded, the distortion of a body due to a stretching force is . . . . . . to the . . . . . . force.

EXPERIMENT 7

Tenacity of Wire

OBJECT. To determine (*a*) the relation between the tension and the elongation of a wire; (*b*) the comparative tenacity of copper, iron, and brass.

APPARATUS. Block for clamping wire; pulley with stem; thumb tacks; weight carrier; slotted weights — 1 lb., 2 lb., 2 lb., 5 lb., 10 lb.; millimeter scale; large-sized needle; magnifier (a cheap convex lens may be used).

MATERIAL. Spools of iron, brass, and copper wire, # 28; sealing wax.

Introductory:

When a load is suspended by means of a cord, the cord stretches. As the suspended weight is increased, the cord stretches further until it finally breaks. A wire or a metal rod behaves in the same way, but the elongation is smaller and not so readily noticed. There is, however, definite elongation. This must be allowed for in the construction of bridges and other structures. By experimenting with fine wire under increasing loads, we can follow all the changes until the wire breaks.

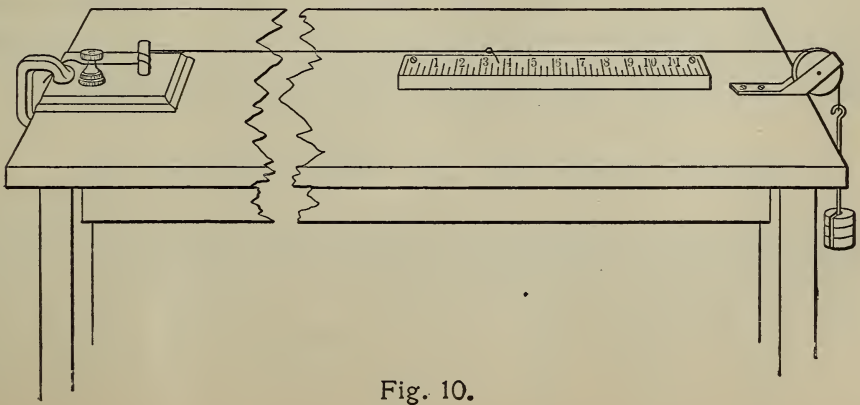


Fig. 10.

Experimental:

(*a*) The block is clamped to one end of the laboratory table and the stem of the pulley set into a hole bored diagonally into the opposite end.

A piece of wire about 30 cm. longer than the table is cut off. This is clamped to the binding post, given a turn around the wooden cylinder, and attached to the weight carrier at the other end. Care must be taken that there are no kinks or sharp bends anywhere in the wire. The wire is then placed over the pulley and the needle attached at right angles to it with a drop of melted wax at a point near the pulley.

The millimeter scale is then fixed in place beneath the the needle with the thumb tacks so that its divisions are parallel to the needle.

A 2-lb. weight is next placed on the carrier to straighten the wire; then it is removed and the zero reading of the needle taken, tenths of the smallest scale division being estimated. A lens may be used to advantage in estimating tenths.

Weights are now added, a pound at a time, the amount of stretching force and the reading of the needle on the scale being noted and immediately recorded in tabular form near the top of the left-hand page.

After each reading remove the weights and again note the zero reading. The force which causes the first considerable shifting in the zero point is known as the *elastic limit.* Continue the readings until the wire breaks.

Observations on —— Wire, Gauge No.

Stretching Force	Zero Reading	Reading of Pointer	Breaking Strength
-----	----	----	----
-----	----	-----	----
etc.	etc.	etc.	etc.

(*b*) Replace the broken wire with another of different material, and add the weights one pound at a time until the wire breaks, without recording the elongations. Repeat with as many wires as the instructor may designate. Record results in tabular form on the second left-hand page.

OBSERVATIONS, PART (*b*)

MATERIAL OF WIRE	GAUGE NUMBER	BREAKING STRENGTH
----	----	-----
----	-----	----

On the left-hand page of the note-book make a simple drawing of your apparatus, and write a simple description of how the experiment was done.

On the right-hand page, at the top, place the calculated results for Part (*a*) in tabular form.

CALCULATED RESULTS

Stretching force	1 *lb.*	2 *lb.*	3 *lb.*,	*etc.*
Elongation	----- *mm.*	----- *mm.*	----- *mm.*,	*etc.*

Curve. — On a piece of cross section paper, plot a curve, laying off forces as abscissæ (horizontal) and elongations as ordinates (vertical) to the scale given by the instructor. *Compare the force at the point where the curve begins to turn with the elastic limit.* Paste the cross section paper by one edge into the note-book.

Discussion:

Does the wire follow Hooke's Law in that "the distortion (elongation) is proportional to the stretching force," through any part of the test as shown by the curve? If so, up to what point?

Conclusion:

(1) State the relation between the tension of a wire and its elongation (*a*) up to the elastic limit, (*b*) beyond the elastic limit.

(2) Arrange the materials tested in the order of their tensile strength, placing the strongest first.

EXPERIMENT 8

Relation between Pressure and Depth

OBJECT. — To find the relation between the depth of a submerged surface and the pressure upon it.

APPARATUS.[1] A test tube loaded with shot, upon which melted paraffin has been poured, so that the tube will float vertically; a paper centimeter scale, attached vertically to the inside of the tube with paraffin; weights — 1 to 10 grams if a $6'' \times \frac{3}{4}''$ test tube is used and 5 to 20 grams if a $8'' \times 1''$ test tube is used; battery jar or hydrometer jar; cross section paper.

Introductory:

When a stick is thrown endwise into water, it springs back into the air. When a boat floats in water, there must be an upward pressure of the water on it to balance its weight. When more heavily loaded, it sinks more deeply, but the upward pressure must then also balance its weight.

Experimental:

A glass tube loaded so that it will remain upright will be floated in a jar of water. A scale on the inside of the tube will be used to measure changes in depth. This

[1] The method of this experiment was called to our attention by Dr. H. C. Cheston of the High School of Commerce, New York City.

tube should float freely and should not be allowed to touch the sides of the jar. The scale readings are taken by sighting through the jar along the under side of the water surface. By adding small weights as indicated in the table below, the level of the bottom of the tube may be changed. By comparing the changes in depth and the changees in weight producing them, we may find how the upward pressure of the water (which balances the weight of the tube) varies with the depth of the surface on which it acts.

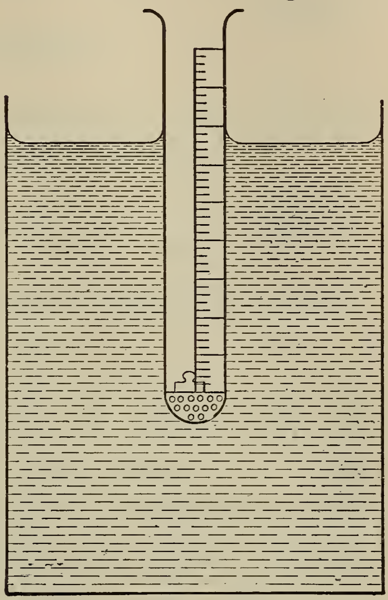


Fig. 11.

Place your observations in a table near the top of the left-hand page.

OBSERVATIONS

Number of Observation	Weight	Scale Reading
1	*Loaded tube alone*	*cm.*
2	*Loaded tube alone* + 2 *grams* . .	*cm.*
3	*Loaded tube alone* + 4 *grams* . .	*cm.*
4	*Loaded tube alone* + 6 *grams* . .	*cm.*
5	*Loaded tube alone* + 8 *grams* . .	*cm.*
6	*Loaded tube alone* + 10 *grams* . .	*cm.*

Make a drawing from your apparatus and write a simple description of the method of the experiment.

Make the following tabulations at the top of the right-hand page:

Calculated Results

Numbers		Change of Pressure		Change of Depth
1 — 2	. . . . .	*grams*	. . . .	*cm.*
1 — 3	. . . . .	*grams*	. . . .	*cm.*
1 — 4	. . . . .	*grams*	. . . .	*cm.*
1 — 5	. . . . .	*grams*	. . . .	*cm.*
1 — 6	. . . . .	*grams*	. . . .	*cm.*

Curve on Cross Section Paper. — The readings of change of pressure and change of depth should be plotted on cross section paper, depths on the perpendicular axis and pressures on the horizontal axis. Use a scale of 5 small spaces to 1 gram, and 2 small spaces to 1 mm. If the resulting graph is a straight line, we may conclude that twice the depth was caused by twice the pressure and so on, or that the pressure is directly proportional to the depth. Paste the cross section paper by one edge in the note-book.

Discussion:

At each observation in the experiment, what relation must exist between the total weight of the floating tube and the upward pressure of the water? Why is it not necessary to consider any sidewise pressures that may be exerted on the tube?

Conclusion:

What is the relation between the pressure on a submerged surface and the distance of that surface below the surface of the liquid?

EXPERIMENT 9

Archimedes' Principle

OBJECT. To determine the relation between the loss of weight of a sinking solid and the weight of a liquid displaced by it.

APPARATUS. Lump of coal with thread, or copper wire #22 attached; overflow can; catch bucket or beaker with wire loop for suspension; spring balance (250 g.), or beam balance; battery jar.

Introductory:

It is much easier to lift the anchor of a boat when the anchor is in the water than when it is out of the water. The displaced water supports part of the weight of the anchor, and so makes it seem lighter, because the upward pressure of the water on the bottom of the anchor is greater than the downward pressure on the top. The anchor displaces a volume of water its own size. We wish to compare the loss of weight of a body submerged in a liquid with the weight of the liquid displaced by it. This was first done by Archimedes, and the relation found is called *Archimedes' Principle.*

Experimental:

Use a piece of coal for the solid. By weighing it *in air*, with a spring balance, and then when *immersed in water* in a jar, the loss in weight of the lump can be found.

When a can with a spout, called an overflow can, is filled and placed on a level table, the water will run out to the level of the spout. By placing a weighed beaker under the spout and carefully lowering the coal into the can, the water which overflows may be caught and weighed. Comparing the weight of this displaced water with the loss of weight of the coal, will give the relation sought.

Record the following readings in tabular form near the top of the left-hand page :

Observations

Weight of coal in air	*g.*
Weight of coal in water	*g.*
Weight of catch bucket	*g.*
Weight of catch bucket + displaced water . .	*g.*

Briefly describe what you did, illustrating each step with a drawing from your apparatus, similar to Fig. 12 (*A*, *B*, and *C*).

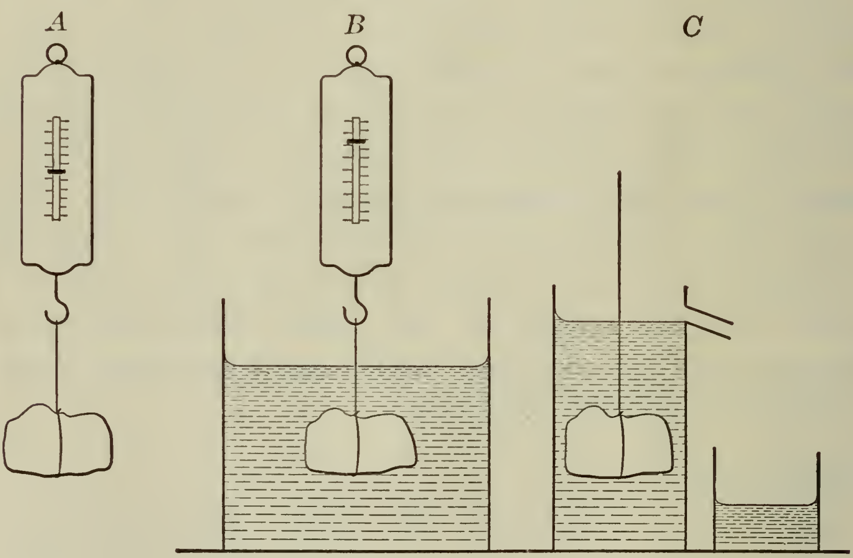


Fig. 12.

Calculated Results

Loss of weight of coal in water	*g.*
Weight of an equal volume of water	*g.*

Conclusion :

State the relation between the loss of weight of a sinking body and the weight of a liquid displaced by it.

EXPERIMENT 10

Law of Flotation

OBJECT. — To determine the relation between the weight of a floating body and the weight of a liquid displaced by it.

APPARATUS. Block loaded to float upright on water; overflow can; catch bucket or beaker with wire loop for suspension; spring or beam balance.

Introductory:

The cork float on a fishline exerts no pull on the line. The weight of an ocean liner is supported by the upward push of the water. A boat is said to have a certain number of tons displacement, depending upon its size and weight. What is the relation between this number of tons of water displaced and the weight of the boat?

Experimental:

A method similar to that used in Experiment 9 will give us the relation between the weight of the wooden block and the weight of the liquid displaced by it. Place the table of observations near the top of the left-hand page.

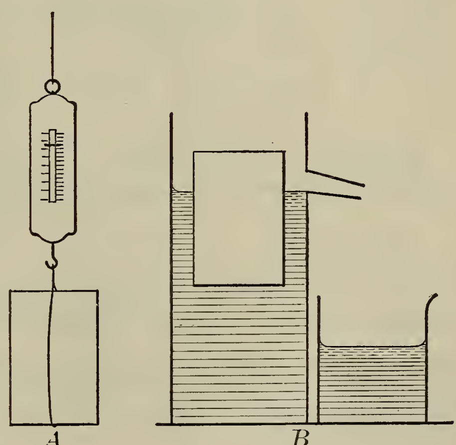


Fig. 13.

OBSERVATIONS

Weight of block	*g.*
Weight of catch bucket, empty	*g.*
Weight of catch bucket + displaced water . .	*g.*

Write a simple description of the steps in the experiment, illustrating each with a drawing from your apparatus.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

Weight of water displaced by floating body . .		*g.*
Comparison of weights	*floating body*	*g.*
	displaced water . . .	*g.*

Conclusion:

The weight of a floating body and the weight of the liquid displaced by it are ——.

EXPERIMENT 10 (Alternative)

Law of Flotation

OBJECT. To determine the relation between the weight of a floating body and the weight of the liquid displaced by it.

APPARATUS. A wooden bar 20 cm. long and 1 cm. square with metric scale attached and loaded so as to be *almost* submerged when floating upright in water;[1] hydrometer jar or battery jar; platform balance; metric weights.

Introductory:

The cork float on a fishline exerts no pull on the line. The weight of an ocean liner is supported by the upward push of the water. A boat is said to have a certain number of tons displacement, depending upon its size and

[1] The ordinary wooden hydrometer can be made available by drilling a hole in the lower end, adding lead shot, and closing with a cork plug. The weight of the bar should be so adjusted that the bar will float *almost* submerged. Finally put a light coat of paraffin over the end which was opened.

weight. What is the relation between this number of tons of water displaced and the weight of the boat?

Experimental:

The wooden bar is to be weighed and then floated in the water of jar so as to note the depth to which it is submerged. The metric scale on the bar gives the length of the column of water displaced and, like the bar the column of displaced water, is 1 centimeter square. Therefore the reading on the metric scale is numerically equal to the number of cubic centimeters of displaced water. Since a cubic centimeter of water at ordinary temperatures weighs approximately a gram, the weight of the displaced water can easily be found. A comparison of the weight of the floating bar and the weight of the displaced water will bring out the principle of flotation.

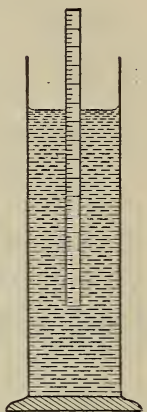


Fig. 14.

Observations

Weight of bar	*g.*
Length of column of displaced water . . .	*cm.*

Make a drawing of the floating bar from your apparatus and write a simple description of the experimental method.

Calculated Results

Volume of water displaced by floating body .		*cm.*^{3}
Weight of water displaced by floating body .		*g.*
Comparison of weights	*floating body* . .	*g.*
	displaced water . .	*g.*

Conclusion:

The weight of a floating body and the weight of the liquid displaced by it are ——.

EXPERIMENT 11

Specific Gravity of Solids

OBJECT. To find the specific gravity of various solids.

APPARATUS. Spring balance, or beam balance arranged for weighing in water; battery jar; pieces of coal, glass, and marble, or other solids desired.

Introductory:

Lead is a very heavy metal. While a pailful of water weighs only about 20 pounds, the weight in pieces of lead that would just fill the pail would be about 225 pounds. Lead weighs about 11.2 times as much as the same volume of water. We say that the "specific gravity" of lead is 11.2 times. The *specific gravity* of a substance is the *number of times* a piece of the substance is as heavy as the same volume of water.

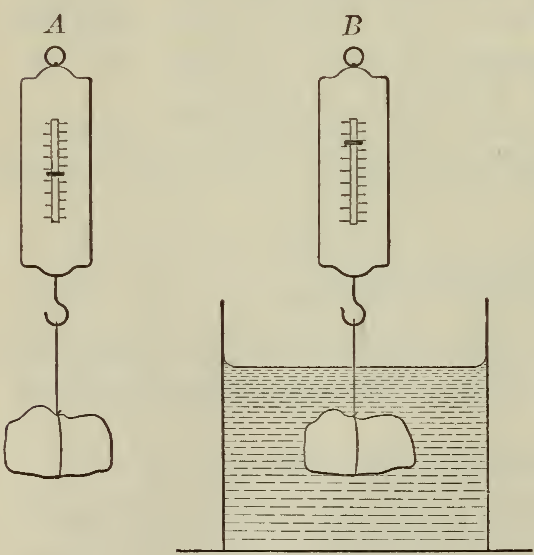


Fig. 15.

Experimental:

It will be necessary to get the weight of a lump of coal and the weight of the same volume of water. The weight of the coal can be found directly with a spring balance, and Archimedes' Principle will help us in getting the weight of an equal volume of water. If the coal is weighed while immersed in water, it will weigh less than

in air by an amount equal to the weight of water having the same size (volume) as the coal. The specific gravity of the other solids furnished may be found in the same way.

Record the weighings in tabular form near the top of the left-hand page.

Observations

	Coal	Marble	Glass
Weight of body in air . .			
Weight of body in water .			

Then make drawings from your apparatus and write a simple description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

	Coal	Marble	Glass
Weight of water size of solid .			
Weight of solid			
Specific gravity of solid . .			

Conclusion:

The specific gravity of coal is ----- times; the specific gravity of marble is ----- times; the specific gravity of glass is ----- times.

EXPERIMENT 12

Specific Gravity of a Liquid

(Bottle Method)

OBJECT. To obtain the specific gravity of a solution of copper sulphate with a specific gravity bottle.

APPARATUS. Specific gravity bottle; spring balance (250 g.) with scale pan, or beam balance; bottle or jar of copper sulphate solution provided with a siphon delivery tube, ending with rubber connection, pinchcock, and glass jet tube (Fig. 17).

MATERIAL. Water; saturated solution of copper sulphate;[1] small cloths for wiping.

Introductory:

If we find the weight of a gallon of water and of a gallon of alcohol, we can directly determine the specific gravity of the alcohol by finding how many times it is as heavy as water. This is a general method for finding the specific gravity of any liquid.

Fig. 16.

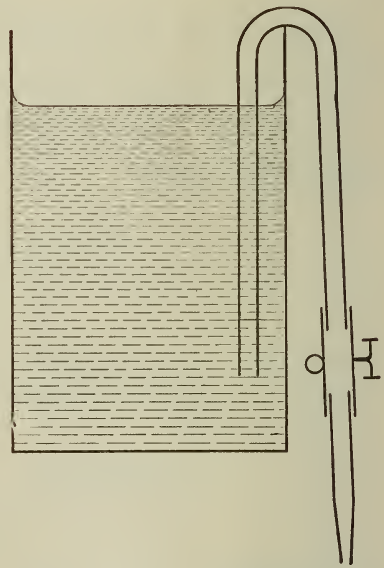


Fig. 17. Jar and siphon for solution.

Experimental:

We use small specific gravity bottles having perforated glass stoppers, as in this way we can

[1] A hot saturated solution should be made and allowed to cool, or a cheesecloth bag full of copper sulphate crystals should be suspended in the top of a jar of water and allowed to stand at least twenty-four hours, or until no more copper sulphate will dissolve.

obtain very exactly equal volumes of the two liquids. The weight of the specific gravity bottle must first be found. Then it is to be weighed full of water and next full of copper sulphate solution. By comparing the weight of the copper sulphate solution filling the bottle with the weight of the water filling the same space, the specific gravity of the copper sulphate solution may be found.

CAUTION. Using the wiping cloths if necessary, see that the bottle is dry on the outside before weighing and avoid handling it except by the neck, for the heat of the hand is likely to drive out some of the liquid through the stopper, after it has been fitted. After the water weighed has been emptied out, rinse the bottle with a little of the sulphate solution.

Record the weighings in tabular form near the top of the left-hand page.

Observations

Weight of scale pan and empty bottle . . . . g.
Weight of pan and bottle filled with water . . g.
Weight of pan and bottle filled with copper sulphate solution . . . . g.

Make drawings from your apparatus and write a short description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Weight of water filling bottle . . . . g.
Weight of copper sulphate solution filling bottle . g.
Specific gravity of copper sulphate solution . . times

Conclusion:

The specific gravity of copper sulphate solution is ----- times.

EXPERIMENT 13

Specific Gravity of a Liquid

(Hydrometer Method)

OBJECT. To find the specific gravity of a copper sulphate solution by the hydrometer method.

APPARATUS. Hydrometer jars; square wooden hydrometer graduated in millimeters; glass hydrometer for heavy liquids (1 to 2).

MATERIAL. Water; saturated solution of copper sulphate as in Experiment 12.

Introductory:

A boat, passing from fresh water into the ocean, rises a little, as the boat displaces its own weight in each case, and the salt water, being more dense, has less volume for the same weight. An electric light bulb in concentrated sulphuric acid floated with 100 c.c. of its volume submerged; in alcohol, which is half as dense as sulphuric acid, the same bulb would sink until 200 c.c. were submerged. We see, then, that the greater the specific gravity of a liquid the less portion of a given floating body will be submerged in it. More exactly, the volumes of a floating body submerged in two liquids are inversely proportional to the specific gravities of the two liquids.

Experimental:

(*a*) A graduated float used for obtaining the specific gravity of liquids is called an *hydrometer*. The hydrometer to be used is a loaded stick 1 cm. square and graduated in centimeters and tenths. If we now immerse this in water (Fig. 18) and record the depth to which it sinks, and then do the same with a copper sulphate solution

(Fig. 19), the hydrometer will sink deeper in the less dense liquid. The volume of each liquid displaced may be measured by the depth of the submerged part of the hydrometer, since each centimeter of length means 1 c.c. of volume. If, then, we divide the length submerged in in water by the length submerged in copper sulphate, we shall obtain the specific gravity of the copper sulphate solution.

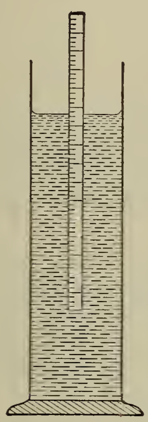


Fig. 18.

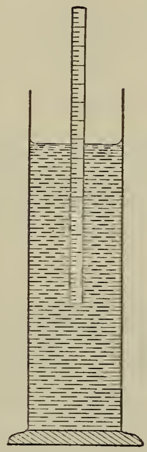


Fig. 19.

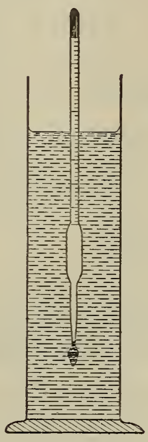


Fig. 20.

(*b*) Direct-reading hydrometers are made of glass tubes loaded so as to float upright and provided with a scale which gives the specific gravity directly (Fig. 20). After completing calculations on part (*a*), ask the instructor for such a hydrometer, and with it find the specific gravity of your solution, as a check on your results. Record the observations in tabular form near the top of the left-hand page.

OBSERVATIONS

Reading of bar in water . . . . cm.
Reading of bar in copper sulphate solution . cm.
Reading of glass hydrometer in copper sulphate solution . . . .

Make drawings from your apparatus showing the position of the wooden hydrometer in the two liquids and the position of the glass hydrometer in the copper sulphate solution. Accompany these drawings with a short description of the method of work.

Calculated Result

Specific gravity of copper sulphate solution as determined by wooden hydrometer . . times

Discussion:

Explain why the volume of water displaced was divided by the volume of copper sulphate solution displaced.

Conclusion:

The specific gravity of the copper sulphate solution
by this method (wooden hydrometer) is ----- times
by the bottle method (Experiment 12) is ----- times
by the direct reading of the glass hydrometer is ----- times

EXPERIMENT 14

Specific Gravity of a Liquid

(Hare's Method)

OBJECT. To find the specific gravity of alcohol and of a salt solution by Hare's method.

APPARATUS. Two 90 cm. lengths of $\frac{1}{4}''$ glass tubing; lead or glass T-tube, or Y-tube; 2 rubber connections; black rubber tubing of length convenient for suction; screw compressor; ring stand and clamp for supporting T-tube or Y-tube; 2 tumblers (preferably of thin glass and with nearly vertical sides), or 2 beakers.

MATERIAL. Distilled water, if available; saturated solution of common salt, and grain alcohol in stock bottles provided with siphon tubes about $\frac{5}{16}''$ bore.

Introductory:

The simple barometer is nothing more than a long tube, closed at one end and filled with mercury, which is then inverted in a dish of mercury. A mercury column about 76 centimeters in length remains standing in the tube. This column is held up by the pressure of the atmosphere. It has also been determined experimentally that the pressure of the air supports a much longer column of water — approximately 34 feet. We know that mercury, volume for volume, is much heavier than water, or, as we say, has a greater specific gravity. The fact that the atmosphere holds up columns of liquid whose length varies with the particular liquid taken, has been utilized in an ingenious method for determining the specific gravity of liquids.

Experimental:

The apparatus (Fig. 21) consists of two long parallel tubes with their lower ends dipping into tumblers of liquids. The upper end of each is joined by a rubber connection to an arm of a T-tube. To the center tube of the T is attached a rubber tube to be used for suction, which can be closed by a screw compressor.

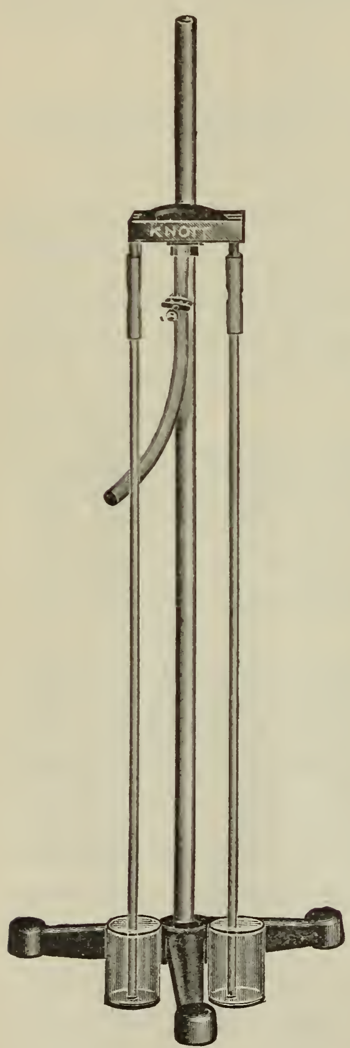


Fig. 21.

(*a*) Half fill one tumbler with water and the other with a saturated solution of salt.

With the rubber tubing open, compare the water levels inside and outside the long tube. *Account for this condition of levels.* Is it also true for the levels of the salt solution?

Suck out a little air through the rubber tube, noting the behavior of the liquids. *What pressure causes the liquids to rise in the tubes?*

Again remove air by suction until the water column is pushed up nearly to the top of its tube. Pinch the rubber tube tightly and close the screw compressor. Note the relative height of the two liquids. The pressure on the upper surfaces of the two liquids is the same. *How does this pressure compare with the outside air pressure? What pressure forced the liquids*

up into the tubes? How does this pressure compare with the downward pressure of each liquid? Compare, then, the downward pressure of the water column with that of the salt solution.

Measure with a meter stick the length of the water column above the level of the water in the tumbler. Obtain similarly the length of the column of the salt solution. Record the measurements in tabular form near the top of the left-hand page.

(*b*) Open the compressor and allow the liquids to run back into their tumblers. Return the salt solution to its stock bottle and rinse out the tumbler. Detach the long tube used for the salt solution, and, after washing, attach it again.

Put grain alcohol into the empty tumbler and repeat the experiment so as to obtain the length of the water and the alcohol columns, *taking care not to suck the alcohol up into the mouth.* Tabulate the measurements near the top of the left-hand page.

Return the alcohol to its stock bottle.

Observations

Part (a):

Length of the water column . . . . . . *cm.*

Length of the salt solution column . . . . *cm.*

Part (b):

Length of the water column . . . . . . *cm.*

Length of the grain alcohol column . . . . *cm.*

Make an outline drawing of the apparatus used, and write a simple description of the general method of the experiment.

With the water and the salt solution, the downward pressure per square centimeter of each, balances the same amount of atmospheric pressure. The two columns must

then have the same weight. Being of equal cross section, their lengths are proportional to their volumes. But the greater the specific gravity of a liquid, the smaller the volume for a given weight. *Are the relative weights, then, directly or inversely proportional to the heights of the columns?* With this relation in mind, calculate the specific gravity of the salt solution and of the alcohol, relative to water. Record the results in tabular form at the top of the right-hand page.

CALCULATED RESULTS

Specific gravity of the salt solution . . —— = *times*
Specific gravity of the alcohol . . . . —— = *times*

Discussion:

Answer under this heading on the right-hand page the italicized questions occurring in the directions.

Conclusion:

The specific gravity of the salt solution is ----- times; the specific gravity of the alcohol is ----- times.

EXPERIMENT 14 (Alternative)

Specific Gravity of Liquids

(Balancing Columns)

OBJECT. **To find the specific gravity of (*a*) carbon tetrachloride, (*b*) grain alcohol, by the method of balancing columns in a U-tube.**

APPARATUS. 2 Mohr burettes (50 c.c.) connected by a piece of thick-walled rubber tubing of sufficient length; Hofmann screw compressor; ring stand; two burette clamps; 2 glass funnels, $2\frac{1}{2}''$, or tops of two thistle tubes; beaker; medicine dropper.

MATERIALS. Mercury; distilled water if available; carbon tetrachloride; grain alcohol. (Other liquids, such as glycerine kerosene, etc., as the instructor desires.)

Introductory:

When mercury fills the lower rounded portion of a U-tube, the mercury stands at the same level in the two arms, since the downward pressure of the air is the same on the two mercury surfaces.

When a certain volume of water is poured into one arm of this same tube, and an *equal* volume of kerosene into the other arm, the mercury level in the water arm is lower than that in the kerosene arm. Since the mercury is free to move, the given volume of water must press down with greater weight on the mercury than does the same volume of kerosene. Accordingly, volume for volume, the kerosene weighs less than the water. Usually the specific gravity is found by calculating the ratio between weights of equal volumes. Since this is so, might not the *inverse* ratio between the volumes of equal weights give the specific gravity?

Experimental:

As we have seen, equal weights may be measured by the downward pressure of liquids. The equal weights can be obtained by pouring just enough of each liquid into its arm of the U-tube, so as to make the two mercury surfaces stand at the same level. All that remains is the measurement of the volumes of the two liquids and the finding of the ratio, remembering that it is an inverse one.

Clamp the two burettes at about a third of their length from their lower ends and in a vertical parallel position with the 50-c.c. marks horizontally opposite each other.

Slip the screw compressor over the rubber connecting tube and attach the ends of the tube to the burettes.

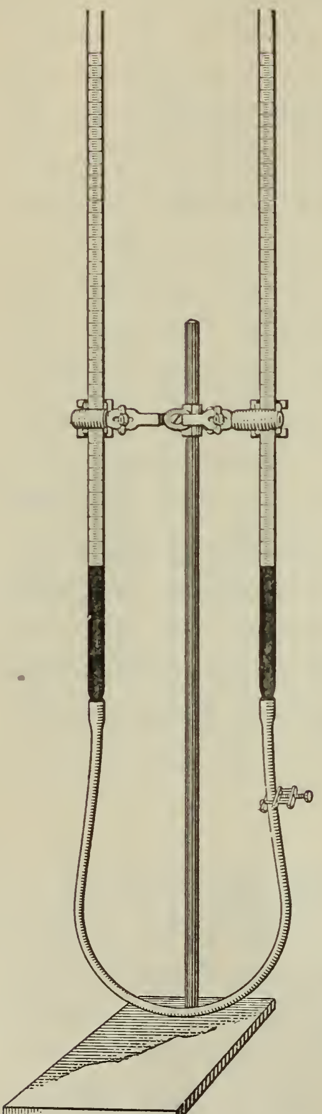


Fig. 22.

Pour mercury through a thistle tube top or funnel at the top of one burette until the mercury surface in each burette stands at the 50-c.c. graduation, or some mark a short distance above (Fig. 22). Squeeze out the air bubbles in the connecting tube before taking the zero reading of the mercury levels.

(*a*) Record the zero reading of the burettes in the table of observations. Then close the screw compressor on the connecting tube.

Into the right-hand burette pour enough carbon tetrachloride to half fill the burette. Add about the same volume of water to the other burette. Cautiously open the compressor a little, noting whether the tetrachloride column is balanced by the water. If not, close the compressor, add more water, and test again. Continue in this manner until the water balances the tetrachloride, as shown by the mercury remaining at the same levels when the compressor is opened wide. A medicine dropper is convenient for adding the last portions of water needed.

Read and record the top levels of the balancing columns.

Raise the tetrachloride burette so that the mercury just runs into the connecting tube. Over this end of the tube

close the screw compressor and slip off the rubber tube, so that the tetrachloride can empty into a beaker placed below the burette. Pour the tetrachloride into its stock bottle.

(*b*) Rinse out the open burette with a few cubic centimeters of alcohol (or other liquid to be used) and again connect the rubber tube.

Then obtain as in (*a*) a column of alcohol which balances the water column in the left-hand burette.

Record all readings in a tabular form near the top of the left-hand page.

Observations

Part (*a*) :

Reading of mercury levels	*cm.*^{3}
Reading at top of water column	*cm.*^{3}
Reading at top of tetrachloride column . . .	*cm.*^{3}

Part (*b*) :

Reading of mercury levels	*cm.*^{3}
Reading at top of water column	*cm.*^{3}
Reading at top of alcohol column	*cm.*^{3}

Make an outline drawing of your apparatus and describe briefly how the experiment was done.

Place the table of calculated results at the top of the right-hand page. The specific gravities are to be calculated with reference to water.

Calculated Results

Part (*a*) :

Volume of the water column	*cm.*^{3}
Volume of tetrachloride column	*cm.*^{3}
Specific gravity of tetrachloride . . ——— =	*times*

Part (*b*) :

Volume of water column	*cm.*^{3}
Volume of alcohol column	*cm.*^{3}
Specific gravity of alcohol . . . . ——— =	*times*

Discussion:

Why is the specific gravity in this experiment the *inverse* ratio of the volumes of the balancing columns?

Conclusion:

The specific gravity of carbon tetrachloride is ---- times. The specific gravity of alcohol is ----- times.

EXPERIMENT 15

Density of Air

OBJECT. To determine the approximate density of air in the room.

APPARATUS. Air pump; round-bottom flask (250 c.c.) with a tightly fitting 1-hole rubber stopper carrying a glass inlet tube with a piece of thick-walled rubber tubing attached; screw compressor; beam or horn pan balance weighing to 0.01 gram; metric weights; graduate; large battery jar, or pail.

Introductory:

It is very evident that lead has weight. Even a small child knows that a tumbler of water is heavier than the empty glass. We know that solids and liquids have weight, but does the air which surrounds us have weight? If balloons are lighter than air, the air must have weight. It would be interesting to find out just how dense air is, that is, the number of grams to a cubic centimeter.

Experimental:

A flask may be weighed full of air and then the air partially pumped out. Then the exhausted flask may be weighed. The difference between the two weights is the weight of air pumped out of the flask. The volume of

this air may be found by measuring the water which will run into the exhausted flask. With the weight and volume of the air known, the density (grams per cubic centimeter) may be found.

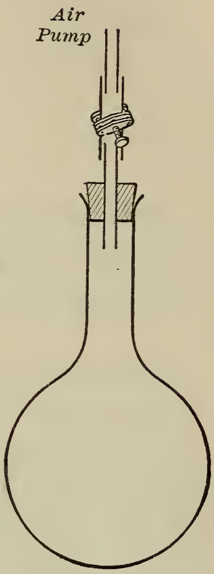


Fig. 23.

Make all weighings to the nearest centigram. In all weighings of the flask, include the rubber stopper with its tubing and screw compressor, and any wire suspension used with the balance. See that all joints between rubber and glass are tight before exhaustion. Allow at least five minutes for the exhaustion of the flask, and be sure the screw compressor is tightly closed before the removal of the rubber tube from the pump.

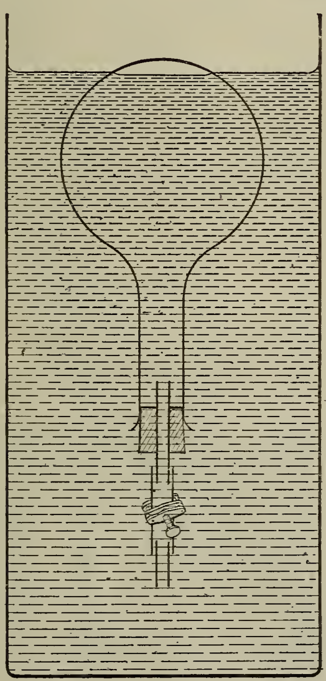


Fig. 24.

Immerse most of the flask in water and open the screw compressor a little at a time under water. As soon as no more water will run in, move the flask so that the level of the water on the inside is the same as that on the outside (Fig. 24).

Pinch the rubber tube with the compressor so as to close it, and remove the flask from the water. Set it in a secure upright position on the table. Open the compressor so as to allow the water in the small tube to run down into the flask and then remove the stopper and its connections.

Measure with a graduate the volume of water in the flask.

Record the measurements in tabular form near the top of the left-hand page.

OBSERVATIONS

Weight of flask filled with air	*g.*
Weight of flask, air exhausted	*g.*
Volume of air exhausted	$cm.^3$

Record, if so directed by the instructor, the temperature of the room and the barometric pressure.

Briefly describe the steps in the experiment, illustrating with drawings from your apparatus.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

Weight of air exhausted	*g.*
Volume of air exhausted	$cm.^3$
Density of air	$\frac{grams}{cm.^3}$

Discussion:

After the water had run into the flask, the water levels were made the same, so that any air not pumped out of the flask would be at the same pressure as the air in the room. What is the necessity for this precaution? Would the results obtained for this experiment be exactly the same on different days? Give reasons for your answer.

Conclusion:

The density of the air in the laboratory at the existing conditions was ----- grams per cubic centimeter.

EXPERIMENT 15 (Alternative)

Density of Air

OBJECT. To determine the approximate density of air in the room.

APPARATUS. Incandescent lamp bulb; Bunsen burner; blowpipe; small battery jar; small funnel and graduate; horn pan balance weighing to 0.01 gram or better; metric weights; small squares of adhesive plaster.[1]

Introductory:

It is very evident that lead has weight. Even a small child knows that a tumbler of water is heavier than the empty glass. We know that solids and liquids have weight, but does the air which surrounds us have weight? If balloons are lighter than air, then air must have weight. It would be interesting to ascertain just how dense air is, that is, the number of grams to a cubic centimeter.

Experimental:

The bulb of an incandescent lamp is empty save for the filament and a very slight trace of gas which was not exhausted. The bulb then can be weighed empty. By making a small hole, the air will rush in and fill the bulb. Another weighing gives the weight of the bulb filled with air. The difference between the two weighings is the weight of the air in the bulb. The volume of this air may be found by filling the bulb with water and then measuring the water with a graduate. With the weight

[1] *Note to Instructor.* If the supply of burnt-out bulbs is limited, the experiment may be done in small squads, each student making the weighings and measurements for himself. In small classes the instructor may prefer to make the first air hole with the blowpipe.

and volume of the air known, the number of grams per cubic centimeter can be calculated.

Filling the Bulb with Air. — Use the tiny point of a blowpipe flame, but approach the portion to be heated very gradually with the flame so as to avoid the sudden cracking and collapsing of the bulb. Heat a small area near the top of the bulb where the diameter is greatest (Fig. 25). As the glass softens at the tip of the blowpipe flame, the pressure of the outside air will make a hole. Any bits of glass which may be chipped off will tend to be drawn inward so that there will be no loss of weight due to the glass. Only a tiny hole is needed to admit the air.

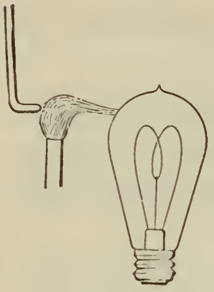


Fig. 25.

Filling the Bulb with Water. — After the bulb has been weighed full of air, heat it with the tip of a blowpipe flame so as to make a little hole in the glass an inch or so from the *base* of the lamp.

When the heated glass is cool, immerse the bulb upright in the water of a battery jar so as to leave the first air hole made just above the surface of the water (Fig. 26). When the bulb is nearly full, incline the bulb, so that the rest of the space can fill with water.

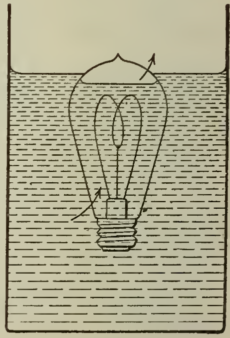


Fig. 26.

Then take the small square of adhesive plaster and stick over the lower hole, holding it in position for a couple of minutes with the finger. Now cover the *upper* air hole with the finger and remove the bulb from the water. Holding the bulb nearly upright over a funnel supported in a graduate, pierce through the adhesive plaster just over the lower air hole. When the finger over the

upper air hole is removed, the water will run down into the funnel. Remember that the outward flow may be stopped at any time by closing the upper hole with the finger.

Record the measurements in tabular form near the top of the left-hand page.

Observations

Weight of incandescent bulb empty	*g.*
Weight of bulb filled with air	*g.*
Volume of air filling bulb	*cm.*^{3}

Record, *if so directed*, the temperature of the air in the room and the barometric pressure.

Describe briefly the steps in the experiment and illustrate with drawings from your apparatus.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Weight of air filling bulb	*g.*
Volume of air filling bulb	*cm.*^{3}
Approximate density of air	$\frac{\textit{grams}}{\textit{cm.}^3}$

Conclusion:

The approximate density of air in room at existing conditions was ----- grams per cubic centimeter.

EXPERIMENT 16

Boyle's Law

OBJECT. **To find how the volume of a gas varies with the pressure exerted upon it.**

APPARATUS. Barometer; Boyle's Law apparatus as furnished by dealers in scientific instruments. The two forms recommended are: (1) the apparatus with the closed tube ending in glass stopcock, and the open tube connected with the closed tube by heavy-walled tubing; (2) the apparatus with both tubes dipping into a mercury reservoir, the closed tube sealed at the upper end, and a small bicycle pump to produce pressure in reservoir, so as to make mercury rise in the two tubes.[1]

MATERIAL. Mercury, if not supplied with the apparatus.

Introductory:

A bicycle pump takes in air and makes it occupy a much smaller space. We know that the air in the inflated tube is under much greater pressure than before. Oxygen is sold in steel cylinders filled under pressure. When the valve is opened, many jars of oxygen may be obtained from one tank for experiments in the chemical laboratory. The total volume of the jars filled is far greater than that of the cylinder, for the oxygen is under much less pressure in the jars than in the steel tank. The two instances of

[1] *Note to Instructor.* The directions for this experiment have been written so that either of the two forms of apparatus may be used. Both forms are on hand in many schools. A good type of the first apparatus may be obtained from the C. H. Stoelting Co., Chicago (list number 1151); the second form with an improved mercury reservoir is made by the L. E. Knott Apparatus Co., Boston (list number 41–105).

The authors regard the J-tube form as very desirable for demonstration purposes, but less fit for the laboratory experiment, as most students are unable to handle it without spilling the mercury required.

the inflated tire and the filling of jars with oxygen show that there is some relation between the volume of the gas and the pressure exerted on it. Whether or not there is any regularity in this relation, may be ascertained by experiment.

Experimental :

Specific directions for handling the apparatus will be given by the instructor.

The volume of air used is that inclosed above the mercury in the closed tube. The mercury in the open tube is used for varying the pressure upon the inclosed air. When the mercury levels are the same in the two tubes, the inclosed air is under atmospheric pressure. When the mercury level is higher in the open tube, then the inclosed air is under more than atmospheric pressure, for a column of mercury equal in height to the *difference in levels* is adding its pressure to the atmospheric pressure. A lower level in the open tube means a pressure less than the atmospheric.

The pressure is expressed in centimeters of mercury. If the bore of the closed tube is of uniform diameter, the length of the inclosed air column may be taken as the measure of its volume and recorded in centimeters.

Make a number of readings, as directed by the instructor. The difference of the mercury levels in the open tube between successive readings, should be about 10 cm. One reading should be made with the mercury at the same level in the two tubes.

As soon as the readings are made, record them in tabular form at the top of the left-hand page.

Write a simple description of the method of using the apparatus and make an outline drawing of it, showing the essential parts.

Observations

Number of Reading	Column of Inclosed Air		Mercury Level Open Tube
	Top	Bottom	
1	cm.	cm.	cm.
2	cm.	cm.	cm.
etc.			

Barometric pressure at---------(time) on---------(date) was---- mm. = cm.

Place the calculated results in tabular form at the top of the right-hand page. The difference in the mercury levels can be found from the quantities in the last two columns of the table of observations.

The pressure of the inclosed air is atmospheric pressure *plus* or *minus* (as the case may be) the difference of mercury levels. In recording the product of the pressure by the volume, omit the decimal fractions.

Calculated Results

Number of Reading	Difference in Levels	Pressure of Inclosed Air	Volume of Inclosed Air	Pressure × Volume
1	cm.	cm.	$cm.^3$	
2	cm.	cm.	$cm.^3$	
etc.				

Discussion:

Is the product of the pressure and the volume approximately constant? Why should the temperature of the inclosed air not change while the readings are being made? Would a variation in the barometric pressure during the experiment affect the result?

Conclusion:

Complete the following statement:

At a constant temperature, the volume of a given mass of gas varies ----- as the pressure sustained by it.

EXPERIMENT 17

Measurement of Gas Pressure

OBJECT. To measure the pressure of the laboratory gas supply.

APPARATUS. Water manometer, consisting of a U-tube (8″) with one arm carrying a tightly fitting 1-hole rubber stopper with glass elbow tube;[1] block with slot or groove for supporting U-tube; foot rule or a metric scale; rubber tubing for connecting manometer with gas cock; barometer.

Introductory:

The bag of a balloon connected with a gas main, fills and rounds out as the gas rushes in. One can feel the gas pressing out when a stopcock is opened from the gas supply in the laboratory. The balloon fills and the gas rushes into the room despite the fact that the weight of the air is pressing around the bag of the balloon and against the opening of the gas cock. This pressure, which is effective against the atmospheric pressure, may be described as the effective pressure of the gas supply. How much is the effective pressure of the gas delivered to our homes and school?

Experimental:

Enough water is added to the U-tube to fill it about halfway up, and then the stopper carrying the elbow tube is pressed tightly into one arm of the tube. The water levels in the two arms are at the same height, since the air presses down on both water surfaces equally.

The elbow tube is connected by a rubber tubing with

[1] Instead of the U-tube, a U-shaped bend of glass tubing with the arms about 8″ long, may be used. A Skidmore stand is very convenient for supporting the U-tube.

the gas supply. The gas stopcock is slowly turned on and the difference in the height of the water levels measured. This measurement should be made as soon as the rising water level reaches its greatest height.

Observations

Atmospheric pressure (barometer reading) . .	*in.*
Difference in height of water levels	*in.*
Time when readings were made	

If the measurements were made in centimeters, change them to inches by multiplying by 0.3937.

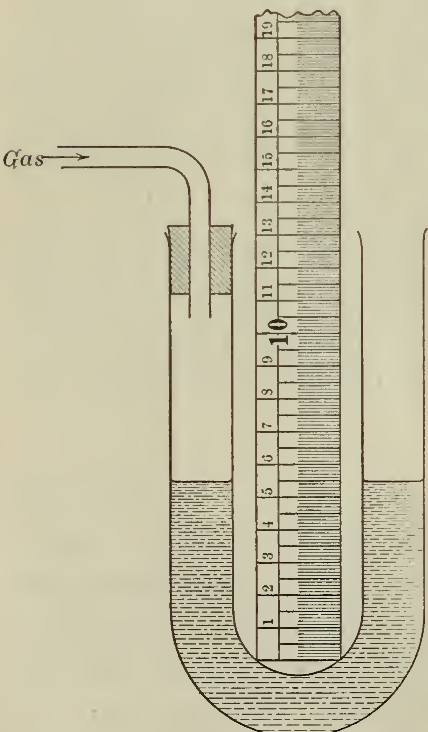


Fig. 27.

Write a simple description of the experiment and make a drawing showing how your apparatus indicated the gas pressure.

The difference of the water levels due to the increased pressure is independent of the cross section of the U-tube, therefore we can consider its cross section to be 1 square inch. A pressure of 14.7 pounds to the square inch holds up a water column 33.57 feet in length. From this equivalent, calculate the pressure in pounds per square inch of a column of water equal in height to the difference of levels measured in the U-tube. This will give the *effective* pressure of the gas.

A pressure of 14.7 pounds to the square inch holds up

a mercury column 30 inches in length. From this relation, calculate the pressure in pounds per square inch which is equivalent to the observed barometric reading.

Adding the effective pressure to the atmospheric pressure gives the *total* pressure of the gas, that is, the pressure per square inch within the gas pipes.

Record the calculated results in a table at the top of the right-hand page.

Calculated Results

Effective pressure of gas per sq. in.	*lb.*
Atmospheric pressure per sq. in.	*lb.*
Total pressure of gas per sq. in.	*lb.*

Discussion:

Why is it not necessary to remove the air in the arm of the U-tube connected with the gas supply? What is the gas pressure stated to be in your town or city? What does this mean?

Conclusion:

The effective pressure of the gas in the laboratory at _____ (time) on _____ (date) was _____ pound per square inch. The total pressure per square inch in the gas pipes was _____ pounds.

EXPERIMENT 18

Water Pumps

OBJECT. To study the parts and the operation of the simple lift pump and the force pump.

APPARATUS. Glass models of a lift pump and a force pump; 3 feet of glass tubing ($\frac{1}{4}''$) with a short piece of rubber tubing attached; battery jar.

Introductory:

The ordinary suction or lift pump has been used for over two thousand years. Although both the lift pump and the force pump are articles of familiar appearance, few can give an intelligent explanation of their operation. In these cases, as in other apparently simple devices, the study of the principles upon which they are based proves fascinating.

Experimental:

CAUTION. Handle the glass models with great care. Do not spill water around the laboratory.

(*a*) Place in a jar of water the lower end of a long glass tube which has a short rubber tube on the upper end. Compare the water levels in the tube and in the jar. Account for the relative levels.

Suck out through the rubber tube most of the air in the glass tube, noting the action of the water. Pinch tightly the upper end of the rubber tube. Does the water run back? *What pressure holds up the column of water in the glass tube?* Release the pressure on the rubber tube. What happens? *Explain. Why is it necessary to remove some of the air in a tube if we want water to be pressed up in it?*

Make three simple diagrams which will show what was done in this part of the experiment and indicate the results.

(*b*) *The Lift Pump.* — Examine a glass model of a lift pump, noting the suction tube, the barrel, the piston, the two valves, and the spout. Make an outline drawing, labeling the parts. Starting without any water in the pump, immerse the suction tube in a jar of water and operate the pump till it is in full action, noting the action of the *inclosed* air, the water, and the two valves on each successive stroke. Record the observations in tabular form on the left-hand page. *What is the main thing accomplished by the first few strokes of the pump?*

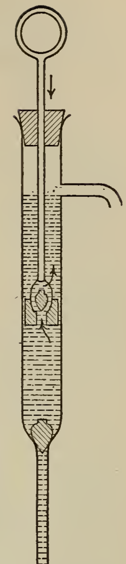


Fig. 28.

OBSERVATIONS ON THE LIFT PUMP

STROKE	VALVE	ACTION OF AIR	ACTION OF WATER	ACTION AND USE OF VALVE
1st Up	Lower			
1st Up	Upper			
1st Down	Lower			
1st Down	Upper			
2d Up	Lower			
2d Up	Upper			
etc.	etc.			

(*c*) By a rubber connection attach a long glass tube to the suction pipe of the lift pump. Dip the free end of the long tube into a jar of water placed on the laboratory floor. Can you pump water from the floor? *What limits the vertical distance through which water can be taken by a lift pump even though it were mechanically perfect?*

(*d*) *The Force Pump.* — Examine the glass model of a force pump, noting its parts. Try its action.

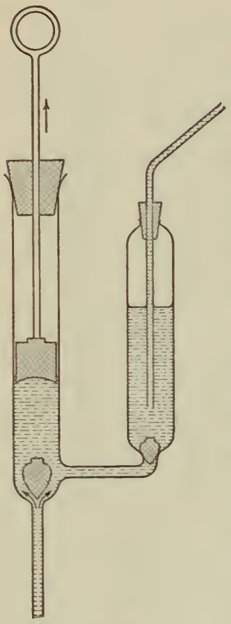


Fig. 29.

Make two diagrams showing the action of the pump — one for the up stroke, the other for the down. Show water levels, and use arrows to indicate the direction of water flow.

Will the force pump or the lift pump raise water to a higher level? *Why is this so?*

Do not write a description of the work done, as the drawings and tabulations show this. A few explanatory statements may be added if necessary.

Discussion:

Under this heading, on the right-hand page, answer the italicized questions in the experimental directions.

Is the action of these pumps due to pressure or to "suction." Which type of pump is a bicycle pump? Explain.

Why is a little water sometimes poured in at the top of a pump just before working the handle? (Class Discussion.)

EXPERIMENT 19

The Principle of Moments

OBJECT. **When three parallel forces are in equilibrium, to compare (*a*) the forces in one direction with the force in the opposite direction; (*b*) the clockwise moments with the counterclockwise moments.**

APPARATUS. Meter stick; loops of strong cord; 3 spring balances (2000 grams), with hooks for suspending them, or clamps for fastening the balances to the edge of the table top (Fig. 35).[1]

Introductory:

When a team of horses is drawing a wagon, their combined force forward is exerted to overcome the resistance of the wagon pulling backward. When two boys carry a heavy weight suspended from a stick, the boys pull upward and the weight pulls downward. If the boys have not equal strength, the weight will be shifted toward one of the boys. Which one?

In each of these cases, we have three forces parallel to each other, two in one direction and one in the other. These forces are in equilibrium when the stick is balanced. If one boy should lift more than he had been lifting, the stick would turn toward him. The turning effect of a force is called *the moment of the force.*

We can imitate either of these cases by attaching three spring balances to a meter stick, so that two pull in one direction and one in the other. We can then compare (*a*) the pull of the two forces in one direction with that

[1] This experiment can also be conveniently done by using two balances suspended vertically with a weight between, supported by a loop on the meter stick so that the weight may be moved to positions of equilibrium. If this modification is made, allowances must be made for the pull on the balances due to the weight of the meter stick.

of the single force in the other, and compare (*b*) the turning effect or moment of the force at one end with that of the force at the other end of the stick.

Experimental:

The apparatus will be arranged as shown in the diagram (Fig. 30). The amount of each force may be read on the balance. First each outside cord should be placed 10 cm. from its end of the meter stick and the third cord in the center. See that all cords are parallel. The highest reading on any balance should not be more than 1600 grams. When all is adjusted, the reading of each balance and the position of each string on the meter stick should be recorded (I).

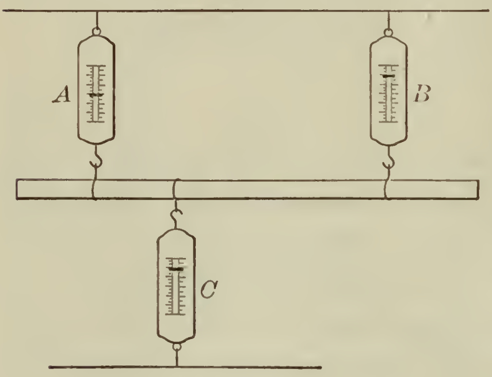


Fig. 30.

One end balance may then be shifted so that it is half as far from the center as the other. After adjustment, readings should again be taken (II). The total force in one direction may then be compared with the total force in the other, as indicated in the table for the right-hand page. The moment of a force is found by multiplying the force by its lever arm. The lever arm is the perpendicular distance from the fulcrum about which the force is trying to turn the body, to the force. In this experiment, the distance between each of the outer cords and the center cord will be the lever arm for the force applied by the cord, if the cords are at right angles to the meter stick. The moment of each of the end forces around the center cord is to be computed.

Record the readings in tabular form near the top of the left-hand page.

OBSERVATIONS

	I	II
Reading of balance A	-----	-----
Reading of balance B	-----	-----
Reading of balance C	-----	-----
Point of application of force A . . .	-----	-----
Point of application of force B . . .	-----	-----
Point of application of force C . . .	-----	-----

Make a drawing of your apparatus and write a simple description of how it was used. Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

	I	II
Combined Force of A and B . . .	-----	-----
Force of C	-----	-----
Moment of A about C	-----	-----
Moment of B about C	-----	-----

Discussion:

Is the moment of A about C clockwise or counterclockwise? Is the moment of B about C clockwise or counterclockwise?

Conclusion:

Complete the following with a statement about the amount of force in each direction:

When three parallel forces act on the same body to produce equilibrium, then__________________________________

Complete the following by comparing with the moment of the third force around the second, both as to magnitude and direction:

When three parallel forces act on the same body to produce equilibrium, the moment of one of them about the second is______________________________________

EXPERIMENT 20

The Lever Arm of a Force

OBJECT. To determine the lever arms of non-parallel forces.

APPARATUS. Meter stick, with a hole on the center division near one edge, drilled slightly larger than the shank of a $\frac{3}{4}''$ screw eye; short piece of board about $\frac{7}{8}''$ stock; screw eye, $\frac{3}{4}''$; fish line; four clamps; half meter stick; draughtsman's triangle, 90°, 60°, and 30.°

Introductory:

In using such a lever as a crowbar, pump handle, or hammer, it is seldom that the forces exerted on and by the lever are parallel to one another. Under such circumstances, it would be desirable to know whether the lever arm is to be measured along the lever or at right angles to the applied force.

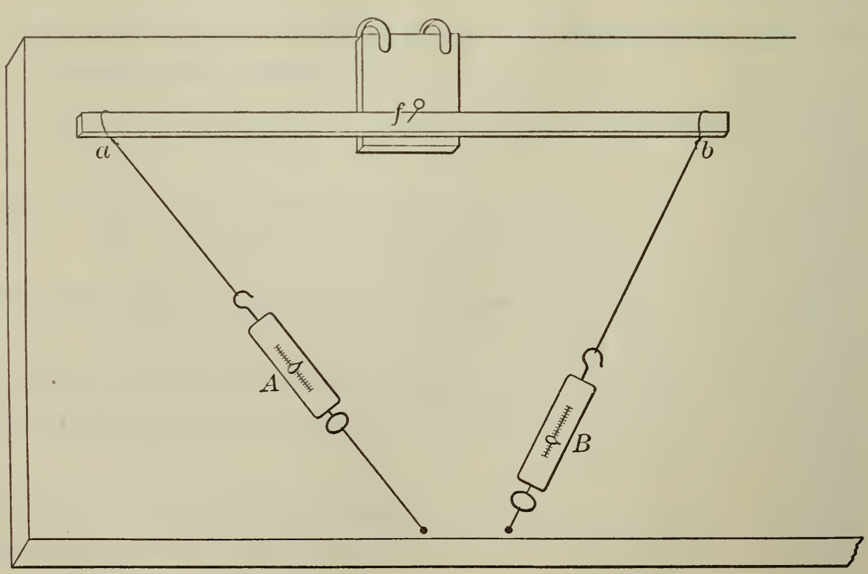


Fig. 31.

Experimental:

The meter stick is to be attached by the screw eye to a short board held firmly by two clamps to the edge of the laboratory table. The meter stick must be free to rotate around the shank of the screw eye as a fulcrum.

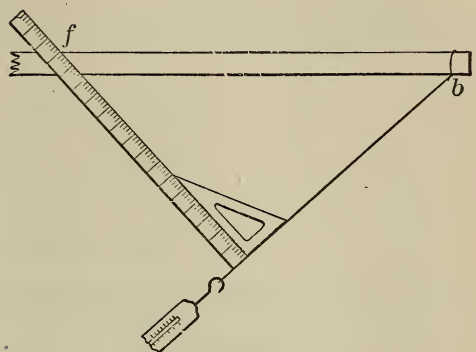


Fig. 32.

The hook of each balance is to be attached by a loop to the meter stick. The other end of each balance is to be clamped to the edge of the table opposite the meter stick. These two balances are to be clamped so that they make acute angles with the meter stick and, if possible, these angles should be different, as shown in Fig. 31.

Perpendicular distances may be measured by using a triangle and a half meter stick, as shown in Fig. 32.

Make the following readings and record in tabular form near the top of the left-hand page of note-book.

OBSERVATIONS

Reading of balance A	*g.*
Reading of balance B	*g.*
Point of application of force A	*cm.*
Point of application of force B	*cm.*
Position of fulcrum on meter stick	*cm.*
Perpendicular distance, fulcrum to force A .	*cm.*
Perpendicular distance, fulcrum to force B .	*cm.*

Make one drawing showing the arrangement of your apparatus and another drawing showing the method of

measuring the perpendicular distance of a force from the fulcrum. Write a simple description of how the experiment was done, referring to the drawings. Place the table of calculated results at the top of the right-hand page and make all the calculations on that page.

Calculated Results

Distance along stick from fulcrum to a . . .	*cm.*
Distance along stick from fulcrum to b . . .	*cm.*
Force A × meter stick distance from fulcrum .	
Force B × meter stick distance from fulcrum .	
Force A × perpendicular distance from fulcrum	
Force B × perpendicular distance from fulcrum	

Discussion:

Which pair of products, in the table above, more nearly agrees with the principle of moments?

Conclusion:

How should the lever arm of a force always be measured?

EXPERIMENT 21

Composition of Several Parallel Forces

OBJECT. When a number of parallel forces are in equilibrium, to compare (*a*) the forces in one direction with the forces in the opposite direction; (*b*) the clockwise moments with the counterclockwise moments.

APPARATUS. Meter stick; four or more spring balances (2000 g.), with cords and clamps.

Introductory:

A floor or bridge beam is frequently supported at more than two points and has a number of different persons or objects exerting their weights on it at various points. It is interesting to determine whether the principle of moments which has been tested for two forces acting about the point of application of a third as a fulcrum, will apply to this case also.

Experimental:

Four or more spring balances, as the instructor may direct, are to be attached by cords to a meter stick, as in

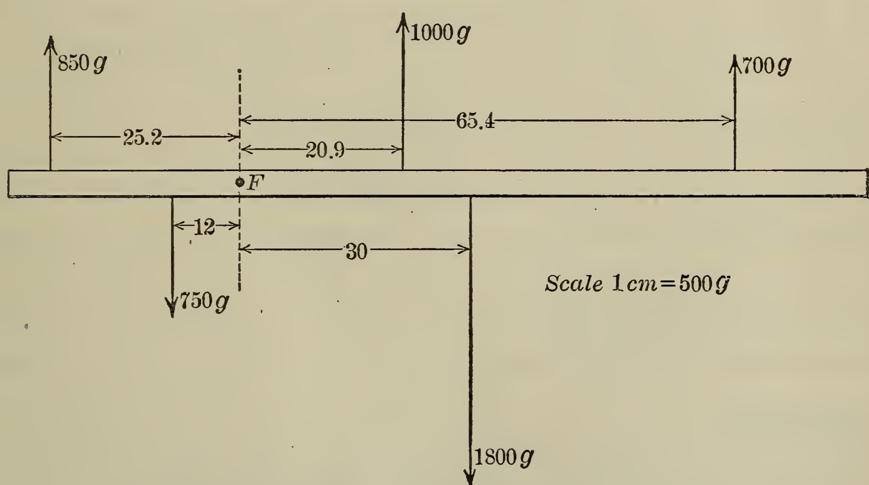


Fig. 33.

the experiment on the Principle of Moments (see Fig. 30, page 78). The balances should then be strained and clamped in place in such a way as to make all the cords parallel, and at right angles to the meter stick.

The amounts of various forces and their lever arms are to be recorded near the top of the left-hand page in the form of a diagram like that shown in Fig. 33. Letter the forces in order from left to right.

Take for the center of moments some point which is *not* the point of application of any of the forces. The line representing each force should be drawn to a scale to be designated by the instructor and the exact amount of the force should be noted at the right of the line representing it. The lever arms are indicated by dimension lines as shown. No drawing of the apparatus will be necessary. A short description, however, of the experimental method should be written.

Place a table like the following at the top of the right-hand page and make all calculations on that page:

Calculated Results

Clockwise Moments		Counterclockwise Moments	
Moment of A	----	Moment of B	----
etc.	----	etc.	----
Total clockwise moments .	----	Total counterclockwise moments	----

Sum of forces as A, C, E, etc. . . . . ----

Sum of forces as B, D, etc. . . . . ----

Conclusion:

Fill in the blanks in the following statement so that it agrees with your results:

When a number of parallel forces act on a body, it is in equilibrium when the ----- of the forces in one direction equals the ----- of the forces in the other direction, and the total ----- moments equal the total ----- moments about *any* point taken as fulcrum.

EXPERIMENT 22

Four Forces at Right Angles

OBJECT. When four forces at right angles in one plane produce equilibrium, to compare (*a*) the force in any one direction with the force in the opposite direction; (*b*) the clockwise moments with the counterclockwise moments.

APPARATUS. Composition-of-force board with under side resting on four steel balls or marbles; four pegs; four spring balances (2000 g.) with cords and clamps; meter stick or other metric ruler.

Introductory:

Four boys of different ages might pull on the four sides of a piece of burlap so as to stretch it parallel to the top of a barrel of vegetables while their father finished the heading by putting on a hoop. Each boy probably took hold of the burlap at the center of his side, but one or more of them soon found it advisable to move his hands to one side or the other of the center, so as to prevent the burlap from being drawn out of his hands. When the burlap was properly stretched, four pulls or forces were acting at right angles in one plane. Did the principle of moments come to the aid of the smaller boys in the family so that they could do their share of the stretching?

Experimental:

The hook of each spring balance is to be attached by a cord to a peg on the composition-of-force board. The pegs should be arranged so that no two of them will be in the same row of holes across the board in either direction. The other end of each spring balance is to be securely clamped (see Fig. 35 on page 89) so that both the cords holding it are parallel to a row of holes (Fig. 34). This

latter figure shows the method of attachment of the balances to the board, but not the correct location of the pegs. The strain on each balance should be at least 500 grams, and the board, which is free to move on its roller bearings, should be brought to rest by the equilibrium of the four forces at right angles pulling on it.

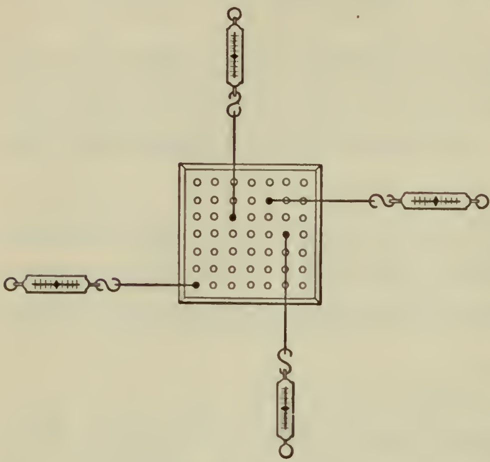


Fig. 34.

The amounts of the various forces and their lever arms are to be recorded in the form of a diagram on the left-hand page. Draw, in about the middle of this page, a square, 7 centimeters on a side, and divide each side into centimeter divisions, and *lightly* rule such cross lines as will locate the positions of the four pegs or points of application of the several forces.

Take for the center of moments some point which is *not* the point of application of any of the forces. *To a scale designated by the instructor*, draw a line representing the direction and the exact amount of each force. Indicate the amount of each force by figures placed to the right of the line representing it. The lever arm of each force is to be indicated by a dimension line as in Fig. 33, on page 83.

Calculated Results

Clockwise Moments		Counterclockwise Moments	
Moment of	----	Moment of	----
etc.	----	etc.	----
		Total counterclockwise	
Total clockwise moments .	----	moments	----

Unless the instructor so directs, make no drawing of the apparatus. A short description of the experimental method, however, should be written.

Place a table, like the one on page 86, at the top of the right-hand page and make all calculations on that page.

Conclusion:

State, when four forces at right angles in one plane produce equilibrium:

(*a*) the relation of the force in one direction to the force in the opposite direction;

(*b*) relation of the clockwise moments to the counter-clockwise moments about *any* point taken as a fulcrum.

EXPERIMENT 23

Parallelogram of Forces

OBJECT. To find the relation between three forces acting on a body at a point, in order that they may be in equilibrium.

APPARATUS. 3 spring balances (2000 g.); fish line or other light, strong cord; 3 Stone clamps or other means of holding balances in place; 30 cm. ruler.

Note. — Pencils used in this exercise should be hard, with long, sharp points.

Introductory:

If two boys were to kick a football, one east and the other north, at the same instant, the ball would not go in either direction, but would take a course somewhere between north and east. The general direction that it would take would depend upon which force were greater. To prevent the football from moving, it would be necessary

to apply a third force which should have the proper direction and amount to just neutralize the other two. We wish to find the relation between three forces at an angle to each other, acting on a body at a point in such a way as to keep the body at rest. With the football it would be possible for a single force to be substituted for the forces applied by the two boys. Such an imaginary force is known as a *resultant* force, and the two forces which it replaces are *component* forces. The single force that would keep the ball from moving is called the *equilibrant* force. Our problem is to find (*a*) how the resultant force is related to the component forces in *direction* and *magnitude;* (*b*) how the resultant force is related to the equilibrant force.

Experimental:

Connect the three spring balances by three cords that meet at a point *A*. Fasten these balances in place by clamping the attached wires. Pull on the third balance until the pointer on one of the balances is near the end of the scale and then clamp the third balance in place.

Place the right-hand page of the note-book under the cords with the center of the page under the point *A*. Mark two points directly beneath each cord. Remove the book and through each pair of points draw a line which represents *in direction* the force. Note and record on the diagram, the reading of each balance, calling the balances *B*, *C*, and *D*. Measure from *A* along each line a distance to represent the magnitude of the force, using a scale of 1 cm. to 250 grams. Place at the end of each line an arrowhead to show the direction of the force.

Select one force as the equilibrant and lay off from *A* the resultant equal and opposite to the equilibrant. On the two lines representing the components, erect a parallel-

ogram and draw the diagonal from *A*. Determine the magnitude of the force which this diagonal would represent. Compare it with the resultant which you laid off and drew.

Mark on the drawing the lengths of the lines and the readings of the balances. No table of results is necessary

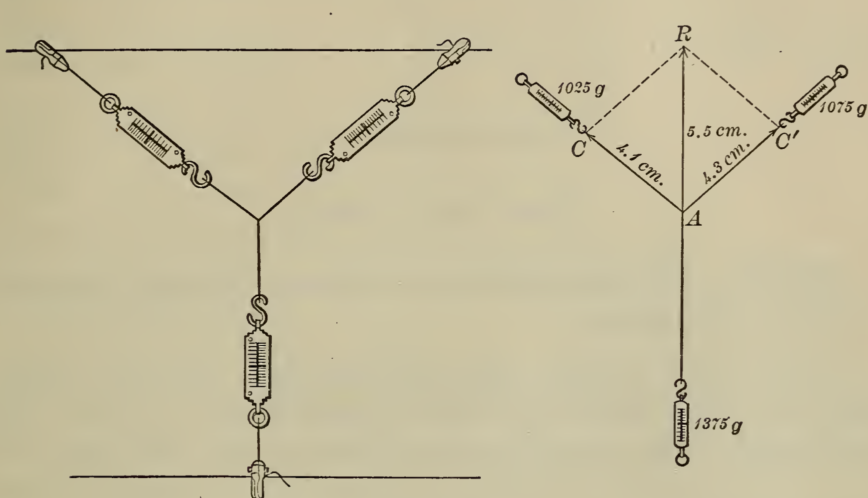


Fig. 35.

on the left-hand page, but write a simple description of the method of the experiment. The drawing has already been placed on the right-hand page.

On the second right-hand page place the table of calculated results.

Calculated Results

Magnitude of resultant	*g.*
Magnitude represented by diagonal	*g.*

Discussion:

(1) What single force would alone produce the same effect as the two forces represented by the sides of the

parallelogram? (2) Compare the resultant and the diagonal of the parallelogram in direction and in magnitude.

Conclusion:

Three forces are in equilibrium when the _____ of two of them is _____ in magnitude and _____ in direction to the _____.

EXPERIMENT 24

Resolution of Forces

OBJECT. Given the resultant of two forces and one of the forces, to find the other force.

APPARATUS. 2 spring balances (2000 g.); 500-gram weight; fish line; upright, with ring for cord and notch for boom; light hard-wood boom, about 25 cm. long, with a brad in the end.

Introductory:

When a load is hanging from the boom of a derrick, its weight is sustained jointly by the tension of the rope supporting the end of the boom and the outward thrust of the boom. These two forces may then be considered as the component forces, whose resultant balances the weight of the load. If we know the pull on the cord supporting the boom and the weight of the load, we can calculate the thrust of the boom outward.

Experimental:

(*a*) The apparatus is to be set up as shown in Fig. 36. The boom should be horizontal, and when it has been made so, a turn of the cord around the brad in the end of the boom will keep it from slipping. When all adjustments have

been made, hold the note-book with the right-hand page against the boom, and indicate the direction of the forces by dots under the cords and a line drawn along the top of the boom. Place a dot at the end of the boom, immediately under the brad. Leave the apparatus undisturbed while performing the operations of part (*b*).

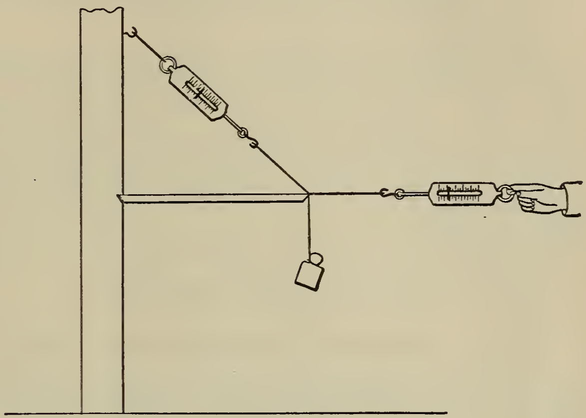


Fig. 36.

(*b*) Replace the note-book on the table. From the dot marking the common point of application of the forces, draw lines through the dots that were placed under the cords. From the common point of application, continue outward some distance the line drawn along the boom. Lay off on the line representing the tension, a distance corresponding to the reading of the balance, using a scale of 100 grams to the centimeter. Mark the end of the measured distance with an arrowhead, indicating the direction of the force. Do the same on the line representing the weight. Mark beside each line the exact number of grams represented.

The weight is the equilibrant of the tension of the cord and the outward push or thrust of the boom against the cord. Therefore draw a line upward from the point of application equal in length to the line representing the weight. With this line as a diagonal and the line representing the tension as one side, complete a parallelogram having a side extending outward from the point of application, as a continuation of the line drawn along the boom.

This side will represent the thrust in direction and magnitude. From the length of this side, the outward thrust of the boom may be calculated, using the scale employed in laying off the other lines.

(*c*) Hook a second spring balance between the cord and the boom and pull horizontally until the boom just slips out of the notch in the upright. Read the balance at this point and record below the drawing on the right-hand page:

Force required to pull out boom . . . . *g.*

Since action and reaction are equal, the inward component of the stretched cord on the boom must equal the outward thrust of the boom on the cord.

Make a simple sketch of your apparatus and write a brief description referring to the sketch.

Discussion:

May the resultant of two forces ever be less than one of them?

Is a rope that is just strong enough to lift a weight vertically, strong enough to lift that weight by means of a horizontal boom derrick?

Conclusion:

Given the resultant of two component forces and one of the components, state how the other component may be found.

EXPERIMENT 25

Force at the Center of Gravity of a Body

OBJECT. **To find what is the gravitational force acting at the center of gravity of a body.**

APPARATUS. Half meter stick loaded at one end;[1] ruler or other fulcrum properly supported (see Fig. 37); 200-gram weight with loop of cord attached; spring balance, or platform balance; metric weights.

Introductory:

When we shut a heavy door, we push near the outside of the door and not near the hinge. A small boy can balance a large boy on a seesaw, by sitting farther out on the board. When a body is to be turned about an axis, the turning power depends upon how much force is exerted and how far from the axis the force is exerted. The *turning power* of a force is called the *moment* of that force and is measured by the product of the force and its distance from the axis. The moment of the small boy on the seesaw is equal to the moment of the large boy. If we know the moment of the large boy and the distance of the small boy from the fulcrum, we can calculate what the small boy weighs. If both boys get off, the board can be balanced so it will not touch at either end. The point at which a body must be balanced in order to support it is called the *center of gravity* of the body.

Experimental:

The body will be a half meter stick loaded at one end. This is first to be balanced over a fulcrum in order to find

[1] The loading may be done by attaching a strip of brass, iron, or lead to one end of the half meter stick, at right angles to the stick.

the center of gravity (Fig. 37, *A*). Then a 200-gram weight will be hung about 10 cm. from the free end of the bar and the bar again balanced.

By measuring the distance of the 200-gram weight from the fulcrum and multiplying this distance by the weight (200 g.), the moment of the 200-gram weight is obtained.

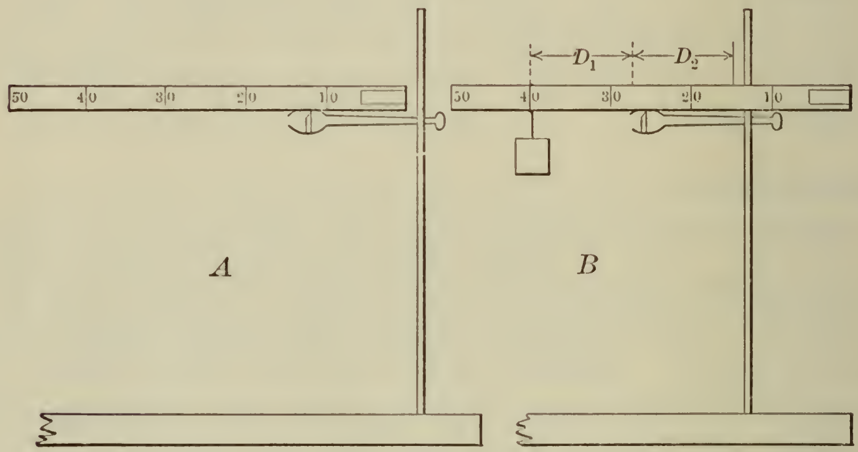


Fig. 37.

This moment equals the moment of the force at the center of gravity about the fulcrum. Then the force at the center of gravity is calculated.

A second trial should be made with the weight at some other point on the stick, as 20 cm. from the end.

Finally the loaded stick is weighed.

All observations as soon as made should be recorded in tabular form near the top of the left-hand page.

Observations

	1	2
Position of center of gravity of loaded stick	-----	-----
Position of 200-g. weight	-----	-----
Position of fulcrum for equilibrium .	-----	-----
Weight of loaded stick	-----	-----

Make drawings showing how your apparatus was used and write a simple description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

	1	2
Distance of weight from fulcrum (D_1)	-----	-----
Distance of center of gravity from fulcrum (D_2)	-----	-----
Moment of weight about fulcrum ($200 \times D_1$)	-----	-----
Moment of force at center of gravity	-----	-----
Calculated force at center of gravity	-----	-----

Discussion:

Define *moment of force.* Explain the calculation of the moment of the force at the center of gravity and the calculation of the amount of this force.

Conclusion:

What gravitational force acts at the center of gravity of a body. (Compare the last item in both tables.)

EXPERIMENT 26

The Pendulum

OBJECT. To observe the effect on the number of vibrations of a pendulum in one minute of (*a*) change in mass, (*b*) change in amplitude, (*c*) change in length.

APPARATUS. A wood and a metal ball each about 1 inch in diameter and having a light cord about 125 cm. long attached; a support consisting of a split cork in a burette clamp, or a special pendulum clamp, so placed that the pendulum may swing freely in front of the laboratory table; metronome or laboratory clock with telegraph sounder.

Note. — Some instructors prefer to have all pendulums in the room released at a given signal and stopped on signal at the end of the minute, as confusion is thereby lessened and the student's mind is concentrated on the counting.

Introductory:

When a clock goes too fast, should the pendulum be shortened or lengthened? We see pendulums made of different materials. Does this affect the length of their beats? Does it take a pendulum longer to swing through a long arc than a small one? These are some of the questions the experiment will help to answer. By a *vibration* of a pendulum is meant a swing from one end of its arc to the other. The *period* of the pendulum is the time that one vibration takes. A *seconds pendulum* is one that swings from one end of the arc to the other in just one second; a half seconds pendulum makes one vibration in one half second; etc. The *frequency* of the pendulum is the number of vibrations per minute.

Experimental:

There will be furnished a metal and a wooden ball of the same size, attached to a light cord over a meter

long. As the suspending cord is very light, we neglect its weight and consider the length of the pendulum as the distance from the lower edge of the support to the center of the suspended ball or "bob."

For the first test, adjust the length of the pendulum with the wooden ball to 100 cm. Count and record the number of vibrations made in one minute swinging through a small arc. Replace with the metal pendulum and find how many vibrations that makes in one minute swinging through the same arc. Comparing these numbers will show whether or not the material of the pendulum affects the period of vibration.

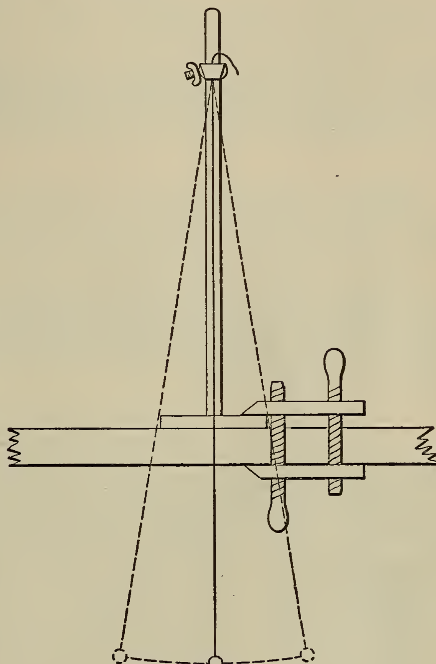


Fig. 38.

Now swing the metal bob through an arc twice as great as before, counting the number of vibrations per minute. Make the length of the pendulum 50 cm. and find the number of vibrations per minute. Repeat with lengths of 36 cm. and 25 cm.

Record all observations in tabular form near the top of the left-hand page.

Observations

Vibrations per minute, bob wood, length 100 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 100 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 100 *cm., arc large* . . . . -----
Vibrations per minute, bob metal, length 50 *cm., arc small* . . . . -----
Vibrations per minute, bob metal, length 36 *cm., arc small* . . . . -----
Vibrations per minute, bob metal, length 25 *cm., arc small* . . . . -----

Make a drawing of your apparatus and describe briefly how the experiment was done.

Place the table of calculated results at the top of the right-hand page and directly below make all the calculations called for.

CALCULATED RESULTS

LENGTH	NUMBER OF VIBRATIONS	PERIOD	SQUARE OF PERIOD
100 cm.			
50 cm.			
36 cm.			
25 cm.			

Conclusions:

(*a*) Does the mass of the pendulum affect the period? (*b*) Does the amplitude (if comparatively small) affect the period? (*c*) Is there any simple relation between the period and the length? between the square of the period and the length?

EXPERIMENT 27

The Inclined Plane

OBJECT. **(*a*) To compare the work done in raising a load by means of an inclined plane and in raising it vertically; (*b*) to determine the mechanical advantage from the length and height of the plane.**

Note. — Only the case when the force is *parallel* to the plane is considered in this experiment.

APPARATUS. Inclined plane properly supported; car with cord attached; 500-gram weight or other load; spring balance (2000 g.).

Introductory:

Safe movers roll a safe into a wagon along a sloping plank. Does this require less force than to lift the safe directly into the wagon? Is less work done by rolling it up the incline than by lifting it directly? The plank is an example of the use of the inclined plane. We wish to answer the above questions by using a car on an inclined board in the laboratory. We also wish to find out the *mechanical advantage* of the plane. This is the number which is obtained by dividing the resistance by the effort. In the inclined plane the mechanical advantage may be found also from the dimensions of the plane. We shall seek to find what dimensions are used and what division is made to obtain the mechanical advantage.

Experimental:

An iron car loaded with a 500-gram weight will be used and it is to be pulled up an inclined plane by means of a cord attached to a spring balance. This balance thus measures the force employed to draw the car up the plane.

The combined weight of the car and its load is the weight lifted by the use of the plane. It may be found with the spring balance. The dimensions of the plane are to be measured, as shown in Fig. 39.

Correction is to be made for some friction. This may be eliminated by averaging the reading of the balance when the car is moving uniformly up the incline with the

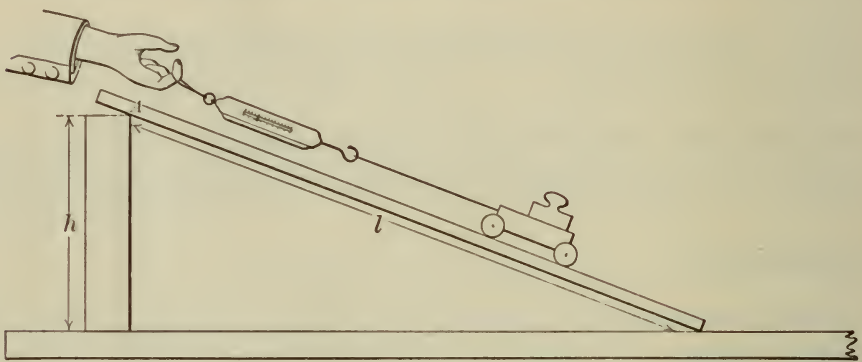


Fig. 39.

reading when it is moving uniformly down the plane. *Decide in each case whether the friction is a help or a hindrance.* The work done along the plane is measured by the product of the balance reading and the length of the plane (to *A*). The work done in raising the weight an equal distance is measured by the product of the weight lifted and the height of the plane (at *A*).

Record the observations in tabular form near the top of the left-hand page.

Observations

Weight of car and load	*g.*
Force required, car ascending	*g.*
Force required, car descending	*g.*
Length of plane	*cm.*
Height of plane	*cm.*

Make a simple sketch of your apparatus and write a short description of the method of the experiment.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Average force used	*g.*
Work = *weight lifted* × *height of plane* . . .	*g.cm.*
Work = *force* × *length of plane*	*g.cm.*
Mechanical advantage $= \dfrac{\textit{weight}}{\textit{force}}$	
$\dfrac{\textit{Length of plane}}{\textit{Height of plane}}$	

Conclusion:

(*a*) Compare work done in lifting the load *vertically* from the table to the level of *A*, with the work done in raising it the same vertical distance by rolling it along the plane. (*b*) What relation between the height and length of the plane equals the mechanical advantage?

EXPERIMENT 28

Pulleys

OBJECT. To study the operation of pulleys and to find their mechanical advantage.

APPARATUS. 1 single fixed pulley and 1 double fixed pulley with stems for clamping or attaching; single movable pulley; an additional movable pulley or a movable double pulley with hooks for suspending pan or weights; support for fixed pulley; balance pan[1]; metric weights; spring balance (250 g.); meter stick; light, strong flexible cord (fish line).

Introductory:

The block and tackle is a familiar sight in large cities, as it is used for moving pianos and safes in and out of high buildings. In the country it is used for pulling stumps and handling logs. On the water front, the pulley in some form or combination is employed for loading the heaviest articles of the cargo.

Pulleys would not be so widely used unless they brought some mechanical gain to their users. The mechanical advantage of a machine may rest in changing either the direction or the magnitude of the force applied to it. Wherein lies the gain when pulleys are used?

[1] The balance pan for *Part* (*a*) is made by first finding with a sensitive spring balance the error in indicated weight arising from the use of the balance tested in an inverted position. The pan is made from thin sheet copper and holes punched in the corners for the fine copper wire used as suspension cords. The weight of the pan and its suspension should equal the weight error found for the balance. It can be adjusted by filing or punching.

Experimental:

(*a*) *The Fixed Pulley.* A spring balance should be used with the hook downward, as the weights of the hook and the drawbar were acting on the spring when the mark for the zero point was located. In an inverted position the balance will not read correctly. To compensate for the error arising in this manner, in this experiment, the balance pan with its supporting cords has been made equal in weight to the drawbar and hook.

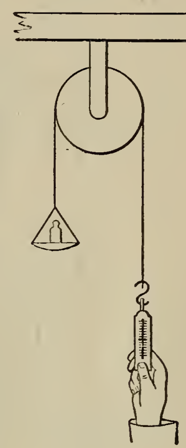


Fig. 40.

The apparatus should be arranged as in Fig. 40. A weight is placed in the pan and the spring balance is pulled vertically downward so as to raise the load at a steady rate, the force or effort necessary being read at the same time on the spring balance. Then the balance reading is again taken as the load descends at a uniform rate. The friction increases the balance reading as the load ascends and decreases the reading for the load descending. An average of the two readings may be considered as the force or *effort* which will just equal the *resistance* to be overcome before the load will move.

Take readings with 100 grams and 200 grams as the loads, and record in tabular form. Note the distance through which the load is raised as compared with the distance through which the effort moves. Compare the load with the effort. *What is the only mechanical gain in using a single fixed pulley?*

(*b*) *Single Movable Pulley.* The apparatus is arranged as in Fig. 41. The total load in this case includes the weight of the pan and the weight of the pulley block. These are weighed separately and the weights recorded.

Readings are made with the 100-gram and the 200-gram weights as in (*a*). How does the distance through which total load (resistance) moves compare with the effort distance? *What is the*

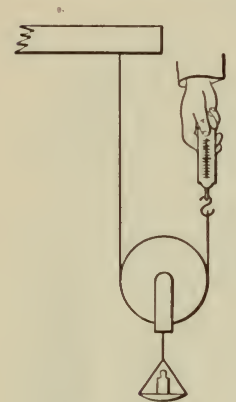


Fig. 41.

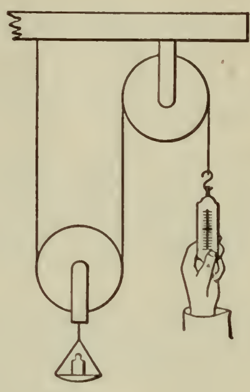


Fig. 42.

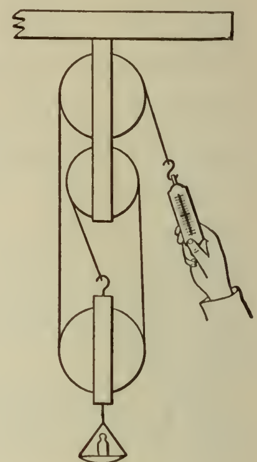


Fig. 43.

mechanical advantage of a single movable pulley? What is sacrificed to gain this?

(*c*) *Combinations of Pulleys.* — A *single fixed* and a *single movable* pulley are arranged as in Fig. 42. This is the arrangement used in the movable scaffolds of house painters. Only one set of readings is made — that with a load of 200 grams. *What additional advantage does this combination of pulleys have over the single movable pulley?*

Next, *two fixed* pulleys (a double pulley) and a *single movable* pulley are combined by the proper adjustment of cords. Readings are taken with the 200- and the 500-gram weights. The vertical distance through which the load moves from the table top is carefully measured as is also the distance covered by the effort at the same time. Note also the number of cords which support the movable block.

Then a *fixed pulley* is combined with *two movable pulleys*

(or a double pulley) and a similar set of ıeadings taken with weights of 200 and 500 grams.

Make for (*a*), (*b*), and (*c*) simple diagrams showing the arrangement of the load, the pulleys, and the spring balance. Indicate clearly the number of cords which support the movable pulley blocks.

Write simple descriptions of the work done in each part of the experiment, shortening the descriptions by references to the diagrams.

Observations

Trials	Pulleys used	Weights of			Balance Reading	
		Load	Pan	Movable Block	Up	Down
1 and 2	1 fixed	100 g.	——	——		
3 and 4	1 fixed	200 g.	——	——		
5 and 6	1 movable	100 g.				
7 and 8	1 movable	200 g.				
9 and 10	1 fixed and 1 mov.	200 g.	——			
11 and 12	2 fixed and 1 mov.	200 g.	——			
13 and 14	2 fixed and 1 mov.	500 g.	——			
etc.	etc.	etc.				

For Part (*c*) *only; Trials* 11 *to* 18

Number of Trials	Resistance (Total Load)	Effort (Average Balance)	Distance moved Through	
			Resistance	Effort
11 and 12				
13 and 14				
15 and 16				
17 and 18				

Except in *Part* (*a*), the total load (resistance) is the sum of the weights on the pan, the weight of the pan, and the weights of the movable blocks used. The average of the two balance readings in each trial is the effort. The *mechanical advantage* of a machine is defined as the resistance divided by the effort. Record these calculated results in a table at the top of the right-hand page.

CALCULATED RESULTS

TRIALS	PULLEYS USED	RESISTANCE (R) (Total Load)	EFFORT (E) (Average Balances)	MECHANICAL ADVANTAGE $R \div E$	CORDS SUPPORTING MOVABLE BLOCK

Discussion:

Under this heading on the right-hand page (or the second right-hand page) answer the italicized questions occurring in the experimental directions.

Conclusion:

After comparing in each case the number representing the mechanical advantage with the number of cords supporting the movable block or blocks, answer the following question:

How may the mechanical advantage of a set of pulleys be stated in terms of the machine's construction?

EXPERIMENT 29

The Wheel and Axle

OBJECT. **To study the operation of the wheel and axle and to find its mechanical efficiency.**

APPARATUS. Wheel and axle with several diameters; metric weights (500 g. and 1000 g.); spring balance (2000 g.) in case apparatus has not an exact simple ratio; fish line; stand and clamp for wheel and axle in case it is not mounted on its own base; pair of calipers (or a pencil compass) is convenient for measuring the radii; meter stick.

Introductory:

The windlass is used to lift a bucket from a well or dirt from an excavation. Several men on a capstan can pull out of the water a heavy anchor which they could not lift with their hands from the deck of the vessel. The devices for accomplishing these rather difficult tasks are applications of the wheel and axle, one of the simple machines. In the illustrations just given, a lesser effort overcomes a larger resistance, or there is a mechanical advantage greater than one. Upon what does the mechanical advantage of a wheel and axle depend?

Experimental:

One cord is attached to the axle and another cord to the wheel. On the axle cord is attached the load (*resistance*); on the wheel cord are attached weights which act as the *effort* and just balance the load. When the weights on the two cords are in equilibrium, *the slightest pull on the cord in either direction should make the weights run freely up and down at a gentle rate.*

The weights may be attached by a slip noose in the

free end of the cord. The first load may be conveniently 1000 grams. The distances traveled by the effort and the resistance in the same time are measured with a meter stick. The radius of the axle and the radius of the wheel are also determined. All these measurements are to be recorded in tabular form near the top of the left-hand page.

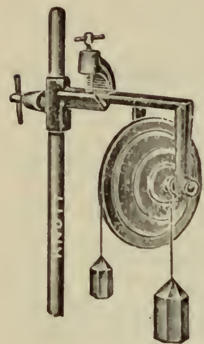


Fig. 44.

At the direction of the instructor, measurements with additional loads are made. In case there are several wheels on the axle, one of the smaller wheels may be taken for a new axle. For some of the measurements it may prove necessary to use a spring balance in place of the effort weight.

OBSERVATIONS

NUMBER OF TRIAL	LOAD ON AXLE (Resistance)	EFFORT ON WHEEL	RADIUS OF AXLE	RADIUS OF WHEEL
1	1000 g.			
2				
etc.	etc.			

For Two Readings Only

NUMBER OF TRIAL	LOAD (Resistance)	EFFORT	DISTANCE MOVED THROUGH	
			Resistance	Effort

Make a drawing of the wheel and axle used and write a simple description of how the experiment was done.

The mechanical advantage of a simple machine like the wheel and axle, is *the ratio of the resistance to the effort.* Calculate this for each trial. Also find in each case *the ratio of the radius of the wheel to the radius of the axle.* Place all the calculated results in tabular form at the top of the right-hand page.

CALCULATED RESULTS

NUMBER OF TRIAL	RESISTANCE (R) (Load)	EFFORT (E)	MECHANICAL ADVANTAGE $R \div E$	$\frac{\text{RADIUS WHEEL}}{\text{RADIUS AXLE}}$

Discussion:

What is sacrificed in gaining the mechanical advantage of the wheel and axle?

Conclusion:

Complete the following statement: The mechanical advantage of the wheel and axle may be stated in terms of its construction as the ratio of the ---------------- to the ----------------

EXPERIMENT 30

Mechanical Efficiency of Machines

OBJECT. — To find the mechanical efficiency of an inclined plane, a set of pulleys, and a wheel and axle.

APPARATUS. As designated for the inclined plane (page 99), for the pulley (page 102), and for the wheel and axle (page 107).

In the experiments on those machines, measurements were made and tabulated which will serve for this experiment.

Commercial block and tackle with necessary weights in case Part (*b*) is to be done.

Introductory:

The rapid growth of the manufacturing industries in the United States has been due in large part to the development of efficient machinery. To be efficient, a machine must return, in some form of useful output, a large part of the energy applied to it. Machines which waste too much of the applied energy in friction, in loss of motion, or in other ways, are condemned to the scrap heap when a more efficient machine for the same purpose is devised. Calculations of the efficiency of complicated machinery are difficult even for a competent mechanical engineer, but a student can learn from the inclined plane, the pulley, and the wheel and axle, the main factors in the efficiency of any machine. These factors are in accordance with the *law of work*, — " the amount of work put into a perfect machine equals the work gotten out of it."

The *mechanical efficiency* of a machine is the percentage of total work done on the machine which proves useful.

Experimental:

(*a*) The instructor may direct the use of the readings obtained in the experiments on the inclined plane, the

pulley, or the wheel and axle. In all cases, the effort readings used must be ones taken while the weight (resistance) is being *raised*, *without correction for friction*. These are the conditions under which a machine does *useful* work.

The weight raised, the height of the plane, the force with load ascending, and the length of the plane are the readings to be taken from the inclined plane experiment.

It should be noted with regard to the inclined plane that the load (resistance) moves through a *useful* distance equal to the height of the plane while the effort is moving the length of the plane. The effort is the force used with the load ascending.

In the pulley and the wheel and axle experiments, most of the readings necessary for this experiment were tabulated in the second table of observations. The *effort* reading to be taken from the pulley experiment is not the "average balance," but the balance reading with the load ascending, recorded in the first table of observations.

The observations taken from previous experiments should be again tabulated near the top of the left-hand page used for this experiment. Any new observations made at the direction of the instructor may be tabulated in the same form.

(*b*) During the laboratory hour, if the instructor so directs, a test will be made on the efficiency of a *commercial* block and tackle with as large a load as is safe and desirable. The students designated by the instructor to make the test will report the results to the class. Comparison can then be made between the school apparatus, designed to show the *law* of work, and commercial apparatus, made to stand the wear and tear of actual service.

In a perfect machine, the amount of work obtained from it equals the amount of work put into it, *i.e.* resist-

ance × resistance distance = effort × effort distance. Calculate these two products for each observation.

Then calculate the mechanical efficiency of each machine from the two products, recalling that

$$\text{Efficiency} = \frac{\text{useful work (work output)}}{\text{total work (work input)}}.$$

OBSERVATIONS

MACHINE	RESISTANCE (Load or Weight lifted)	EFFORT (Force applied)	DISTANCE MOVED THROUGH	
			Resistance	Effort

At the top of the right-hand page tabulate the results of all calculations.

CALCULATED RESULTS

MACHINE	USEFUL WORK (Resistance × Resistance Distance)	TOTAL WORK (Effort × Effort Distance)	MECH. EFFICENCY $\left(\frac{\text{Useful Work}}{\text{Total Work}}\right)$

Discussion:

What may make the mechanical efficiency vary in different observations of the same machine?

Conclusion:

The *average* mechanical efficiency found from my observations was for the inclined plane ------ %, for the ------ pulleys ------ %, and for the wheel and axle ------ %.
(state combination used)

EXPERIMENT 31

Coefficient of Friction

OBJECT. To determine the ratio of the friction between two surfaces to the pressure holding them together.

APPARATUS. Rectangular wooden block; board with uniform surface, with support for use as inclined plane; spring balance (2000 g.); fish line; block of weights; meter stick.

Introductory:

Heavy loads on a wagon press down and increase the friction at the axles. The ratio between the friction and the pressure causing it, is called the *coefficient of friction*.

This fraction has different values according to the kinds of surface in contact. For instance, there is more friction between rubber soles and a polished floor than between leather soles and the same floor. The man with the rubber soles can walk up a steeper plank, but even he will begin to slip when the pitch of the plank is increased to a certain definite angle. The leather soles slip at a smaller definite angle of pitch.

The coefficient of friction may be found, either by measuring both friction and pressure directly, or by finding the angle of elevation of the surface of one body, at which the weight of a second body will just cause the latter to slip down the inclined surface of the first.

Experimental:

(*a*) A hard wood block, with various weights upon it, is dragged over the surface of a smooth horizontal board by means of a cord attached to the block and to a spring balance. If the block is kept moving at a uniform speed,

the reading of the balance will show the amount of the friction between the surfaces. The pressure between the

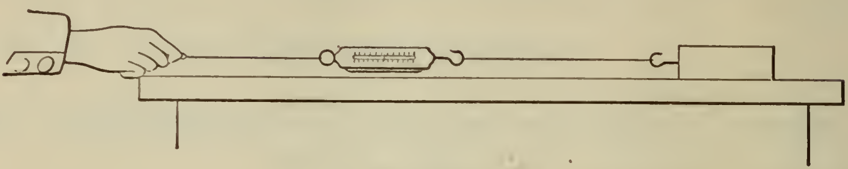


Fig. 45.

surfaces is the weight of the block *plus* the load placed upon it. Several weights ranging from 100 to 1000 grams should be used to load the block. From these readings the coefficient of friction may be found by dividing the friction by the pressure causing it.

(*b*) Using the same block and board, with a support to adjust the board to any desired inclination, the board may

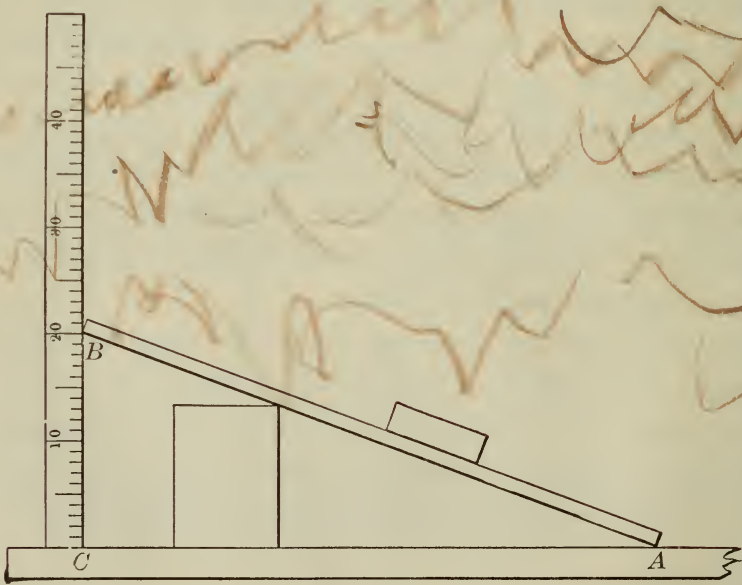


Fig. 46.

be raised gradually until the unloaded block will just slide down with uniform motion if the board is constantly tapped with the finger. This angle is called the *limiting*

angle of friction. Referring to Fig. 46, AC and BC should be measured.

When a body rests on an inclined plane, its weight, w, is resolved into two component forces. One of these, p, is perpendicular to the plane and produces pressure upon it. The other component f acts parallel to the plane and toward the lower end. As this is the only component of the force that acts in the direction in which the body on the plane may move, it is evident that only this force needs to be balanced to keep the body from moving down the plane. Therefore, at the limiting angle, the component f of the weight w, as it urges the block down the plane, just balances the friction.

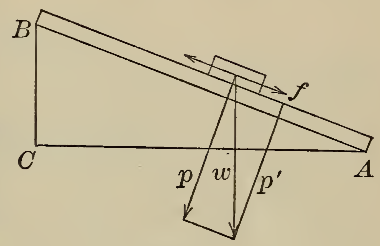


Fig. 47.

It will be readily seen (Fig. 47) that the triangles fwp' and ABC are similar. Hence, $\frac{f}{p} = \frac{BC}{AC}$. But $\frac{f}{p}$ is the friction divided by the pressure and is, therefore, the quantity we seek. Its value, then, may be calculated by dividing the height of the plane by the length of the base.

Record the readings in tabular form near the top of the left-hand page.

Observations

Part (a):

	1	2	Etc.
Total pressure (block and weight)	----- *g.*	----- *g.*	----- *g.*
Reading of balance	----- *g.*	----- *g.*	----- *g.*

Part (b):

Height of plane . . . . *cm.*
Length of base . . . . *cm.*

Make a clear outline drawing of your apparatus and briefly describe your work in both (*a*) and (*b*).

Place the calculated results in tabular form at the top of the right-hand page.

CALCULATED RESULTS

Part (*a*) :

Coefficient of friction $\left(\dfrac{friction}{pressure}\right)$

1	2	3	Etc.	Average
-----	-----	-----	-----	-----

Part (*b*) :

Coefficient of friction $\left(\dfrac{height}{base}\right)$ -----

Discussion:

Is the coefficient of friction dependent upon the load? Show why the ratio of the height to the base of the inclined plane at the limiting angle is equal to the coefficient of friction.

Conclusion:

The coefficient of friction between ----- and ----- is
(name materials)

-----.

EXPERIMENT 32

Vibrations of a Tuning Fork

OBJECT. **To determine the frequency of a given tuning fork.**

APPARATUS. A low frequency tuning fork (not over 128 V.P.S.) with considerable amplitude of vibration, preferably made of bell metal, and with a bristle or stylus attached; oval piece of wood; glass plate smoked; pendulum beating known fraction of a second, provided with a stylus; rigid clamps for tuning fork and pendu-

lum; holder and track for glass plate; candle, or cake of "Bon Ami."

Note. — Apparatus dealers furnish sets of the above apparatus.

Introductory:

A knowledge of the number of vibrations corresponding to each musical note is essential to the understanding of the Physics of Sound. While the ear may be trained to estimate very closely the pitch of the tuning fork, the eye is not quick enough to count its vibrations. By providing the fork with a tracing point and by drawing prepared glass or paper under the fork at right angles to the direction in which the fork is vibrating, each complete back and forth vibration of the fork will be represented by a wave-shaped mark. If a pendulum provided with a tracing point is so placed that it also vibrates across the glass, the distance the glass moved during the known period of the pendulum is also recorded. Then the number of vibrations of the tuning fork in that period may be counted.

Experimental:

The best way of preparing the glass is to rub over it a thin coat of "Bon Ami" or of whiting and alcohol, and allow it to dry. The apparatus should then be carefully inspected and adjusted so that the tracing points of both the fork and the pendulum will sweep across the plate in as nearly the same line as they can without interfering with each other. The tracing points must bear on the surface hard enough to scratch away the coating, but not with pressure enough to check the motion of either fork or pendulum. This may be tested by setting each in vibration with the glass at rest.

The fork is best set vibrating by placing between the

prongs an oval stick of wood, thick enough to spread the prongs the desired amount, and then suddenly pulling it out.

When all adjustments are made, set pendulum and tuning fork in vibration and with a steady, even motion draw the glass along the track at such a rate as to have

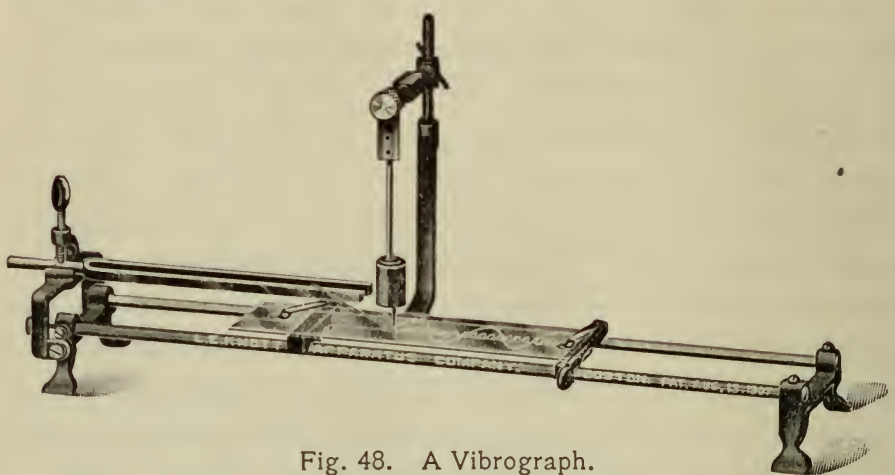


Fig. 48. A Vibrograph.

at least one complete swing of the pendulum, back and forth, recorded on the glass. Remove the glass, to permit others to use the apparatus.

The number of *complete* wave forms traced by the fork between two *successive* points where the pendulum wave crosses the tuning fork wave, is the number of vibrations made by the tuning fork in the period of the pendulum.

Place in tabular form, near the top of the left-hand page, the time of the pendulum period and the number of vibrations recorded each time during that period.

OBSERVATIONS

Trial	1	2	3	4
Observed vibrations .	------	------	------	-----
Period of pendulum .	-----	-----	-----	------
Number of fork . . .	-----			

Make a simple drawing of your apparatus and describe briefly the essentials of the method.

Calculate the average number of vibrations for the period of the pendulum, and from the average find the number of vibrations per second. Record the calculated results at the top of the right-hand page.

Calculated Results

Average number of vibrations in _____ *sec. was* . . -----

Frequency of fork (vibrations per second) . . . -----

Discussion:

(*a*) Explain fully why a complete wave trace of the fork stands for one vibration of the fork.

(*b*) Why does a half wave trace stand for the period of the pendulum?

Conclusion:

The frequency of fork No. ...... is ..... vibrations per second.

EXPERIMENT 33

The Velocity of Sound in Air

OBJECT. **To determine the approximate velocity of sound in the open air at the existing conditions.**

APPARATUS. Pendulum ($\frac{3}{4}$ sec.) with large-faced bob[1] and mounted in a shallow box; pair of field glasses; measuring tape; two short pieces of board; thermometer.

Introductory:

A flash of lightning is usually seen before the thunder, the sound accompanying the electric discharge, is heard. The steam escaping from the whistle on a distant locomotive may be noticed several seconds before the sound reaches our ears. The flash of a gun is evident before the sound of the discharge is heard. All these illustrations show that sound travels much more slowly than light, and that an appreciable interval is required for a sound to travel any considerable distance. Since light has such great velocity, the time required for it to travel a part of a mile is not measurable by any ordinary means, while the comparatively slow-traveling sound takes a noticeable time for the same distance. These relative velocities make possible a simple method for determining the number of feet per second traveled by a sound.

Experimental:

Mount the pendulum beating three fourths of a second in a shallow wooden box with the cover removed. Stretch

[1] In case a pendulum with a brass bob is not available, a pendulum may be made with a 5-lb. slotted weight and a wooden bar, or a good bob could be cast of lead with a small brass curtain rod inserted, in the cover of a coffee tin or lard pail. Whatever large-faced bob is used, one face should be painted a blue similar to that used in the enameled street signs.

across the box opening an opaque white cloth and in it make a hole the shape and size of the pendulum bob at the center of its vibration. At the back of the hole and on the bottom of the box arrange a white background. The exposed face of the bob should be painted blue, since this color will be readily seen as the bob swings across the opening.

Set the pendulum about 500 feet away, so placed that the bob of the pendulum is several feet from the ground. One student is stationed at the box with two short boards and strikes them together so as to produce a sharp sound every time the bob is at the center of its swing.

Observers should move either toward or away from the pendulum until a position is obtained where the successive sounds produced coincide with the successive swings of the bob across the opening. This means that the sound produced at the center of one beat of the pendulum reaches the observer at the center of the next beat. Then during the time of one beat, the sound travels the distance of the pendulum from the observer. Field glasses will be necessary to see clearly the swing of the bob across the opening.

Make one determination with the wind, and one against it, and record the distances as measured with a tape.

Take the temperature of the air and record in the table of observations.

Observations

Distance of observer to pendulum, with wind .	*ft.*
Distance of observer to pendulum, against wind	*ft.*
Temperature of air	°*C.*

Make drawings showing how the pendulum was set up and describe the method of the experiment.

Calculated Results

Average distance traveled by sound in $\frac{3}{4}$ second *ft.*
Velocity of sound per second . . . . *ft.*

Conclusion:

The velocity of sound per second in the open air at _____ °*C.* was _______

EXPERIMENT 34

Sympathetic Vibrations

OBJECT. To set a tuning fork into vibration by sympathetic vibrations with another fork of the same frequency.

APPARATUS. Two tuning forks of the same frequency,[1] as 256 V.P.S.; tuning fork of different frequency, as 384 V.P.S.; flat cork about 2″ in diameter; 500-gram weight or iron ball with fish line for suspension; support for hanging weight.

Introductory:

When the loud pedal of a piano is pressed, dampers are lifted from the strings so that the strings can vibrate freely. Then a note sung into the piano will make one wire vibrate in response, so that a note of the same pitch can be heard. The sound vibrations produced by the human voice have been the stimulus to the production of a sound by the vibration of one of the piano wires.

[1] *Note to Instructor.* — Two forks stamped with the same frequency number will rarely vibrate at the same rate without filing notches in the end of one of them. Do this by taking two forks that sound nearly alike and than raise the pitch of the lower (flat) fork by filing the outer end of one prong. Then stamp or file an identifying number on the handle of both forks. Always give out together that pair of forks for this experiment.

Since the stimulating sound and the sound produced have the same pitch (frequency of vibration), this is a case of *sympathetic vibrations.* Tuning forks are very convenient instruments for studying sympathetic vibrations, for their rate of vibration per second is known. Usually the frequency number is stamped at the base of the two prongs.

Experimental:

(*a*) Suspend a 500-gram weight (or a ball of about the same weight) by a light, strong cord about a meter in length.

When the weight is at rest, give it a light tap with a lead pencil, noting the direction in which the weight begins to move or vibrate. When the weight is at the center of its swing and *moving from you*, tap again. Continue in this manner until the weight has received about twenty gentle taps. What is the effect upon the vibrations of the suspended weight? From what source did the weight get its impulses?

With the weight again at rest, give it, without paying any attention to the intervals, twenty more gentle taps, hitting the weight just as it happens to be coming toward or going away from you. What is the effect on the vibration of the weight? Compare the regularity in time of this second tapping with that of the first. *What relation existing between the regularity of the tapping and the vibration of the weight, caused such a marked effect in the first case?*

(*b*) The following directions must be followed exactly in order to secure the desired result. Study them thoroughly before beginning the experiment. Examine the forks to see that the same number is marked on the stem of each.

(1) Hold the two forks by the stem, not allowing the

fingers to touch any other part of the fork (in order to avoid heating).

(2) Set the fork held in the right hand into vigorous vibration by striking the end of one of its prongs sharply against a cork on the desk.

(3) Steady the fork in the left hand by allowing the hand to rest against the desk with the fork held horizontally.

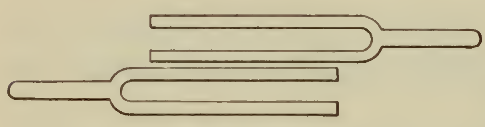


Fig. 49.

(4) Bring the vibrating fork into a position parallel to the other fork, with the prongs extending in an opposite direction and the two forks about $\frac{1}{16}$ of an inch apart (Fig. 49).

(5) After the forks have been in this position while you count three, slowly bring the left-hand fork near the ear and determine whether it has been set into vibration.

(6) If the first trial has not been successful, repeat the work.

Apply to the instructor for a tuning fork of different frequency from that of the two forks used. With this fork and one of the former ones repeat the experiment, noting the success of your efforts.

Make a drawing showing the forks in the position where sympathetic resonance was obtained. Write a full description of the experiment and its results.

Conclusion:

Answer the italicized question in Part (*a*). What must be true of the frequencies of two forks in order that one of them may be set into sympathetic vibration by the other?